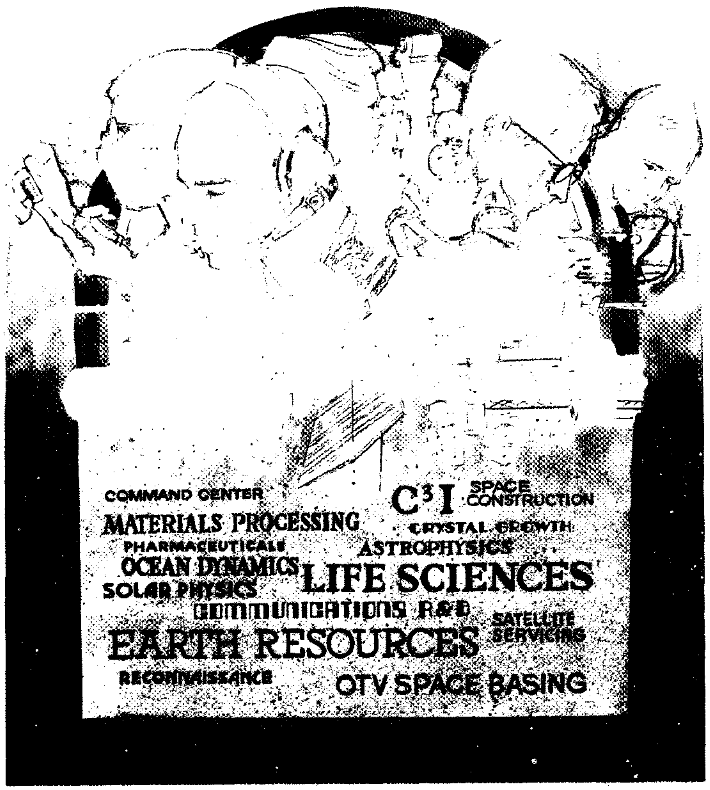
A STUDY OF SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

Midterm Briefing



GENERAL DYNAMICS
Convair Division

Contract No. NASW 3682

A STUDY OF SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

Midterm Briefing

17 November 1982

Presented to
National Aeronautics and
Space Administration

GENERAL DYNAMICS
Convair Division

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	Presenter
Introduction	Don Charhut
Executive Summary	Otto Steinbronn
Mission Requirements	Warren Hardy/Dick Norris
Approach & Data Base	
Mission Requirements	
Integrated Mission Requirements	
Summary of Mission Requirements	
Mission Implementation	John Bodle
Cost & Programmatic Analysis	Bob Bradley
Summary	Otto Steinbronn

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The organization of the General Dynamics management team for this Space Station Needs, Attributes and Architectural Options study is shown on the facing page. The study tasks have been grouped into three major areas: 1) Space Station Utilization, 2) Technical Integration, and 3) Planning. In addition, a special assistant was assigned to assure an effective interface with the DoD community.

A Space Station Advisory Board was also set up to review the progress of work and the conclusions reached prior to each NASA review.

MANAGEMENT TEAM

SPACE STATION PROJECT MANAGER
Otto Steinbronn

SPACE STATION ADVISORY BOARD
Dr. J.P. Waszczak, (Chairman)
Dr. J.R. Arnold
Dr. K.A. Ehricke
Dr. B.J. Bluth
Dr. K.P. Heiss
Dr. A.M. Lovelace

SPECIAL ASSISTANT — DoD
L.R. Norris

UTILIZATION MANAGER
W.G. Hardy

DEVELOP MISSION REQUIREMENTS FOR NASA, CIVIL & DoD USE OF A SPACE STATION (TASK 3.1)

TECHNICAL INTEGRATION MANAGER
J.G. Bodle

PERFORM REALISTIC SYSTEM ARCHITECTURAL OPTIONS AND HARDWARE IMPLEMENTATION PLANS (TASK 3.2)

PLANNING MANAGER
R.E. Bradley

PROVIDE PARAMETRIC COST AND PROGRAMMATIC ANALYSES OF VARIOUS ELEMENTS AND PROGRAM SCENARIOS (TASK 3.3)

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The listed study objectives are extracted from the NASA RFP No. W 10-28647 and are shown here for reference. The major activity during the first phase of the study concentrated on the development of Space Station Mission Requirements.

STUDY OBJECTIVES

Identify, collect & analyze missions that require, or will materially benefit from, the availability of a space station

- Science
- Applications
- Commercial
- U.S. national security
- Space operations

Identify & characterize the space station attributes & capabilities that are necessary to meet these requirements

Recommended mission implementation approaches & architectural options

Recommend time phasing of implementation concepts

Define the rough order of magnitude programmatic/cost implications

A major focus during the first phase of our study was directed towards the development of a broad Space Station interest within the commercial and DoD communities. It was also our objective to identify areas of maximum benefit from a Space Station and initiate detailed analysis activities to accurately quantify the associated economic benefits.

SPECIFIC FOCUS OF GENERAL DYNAMICS STUDY
Initial Study Phase

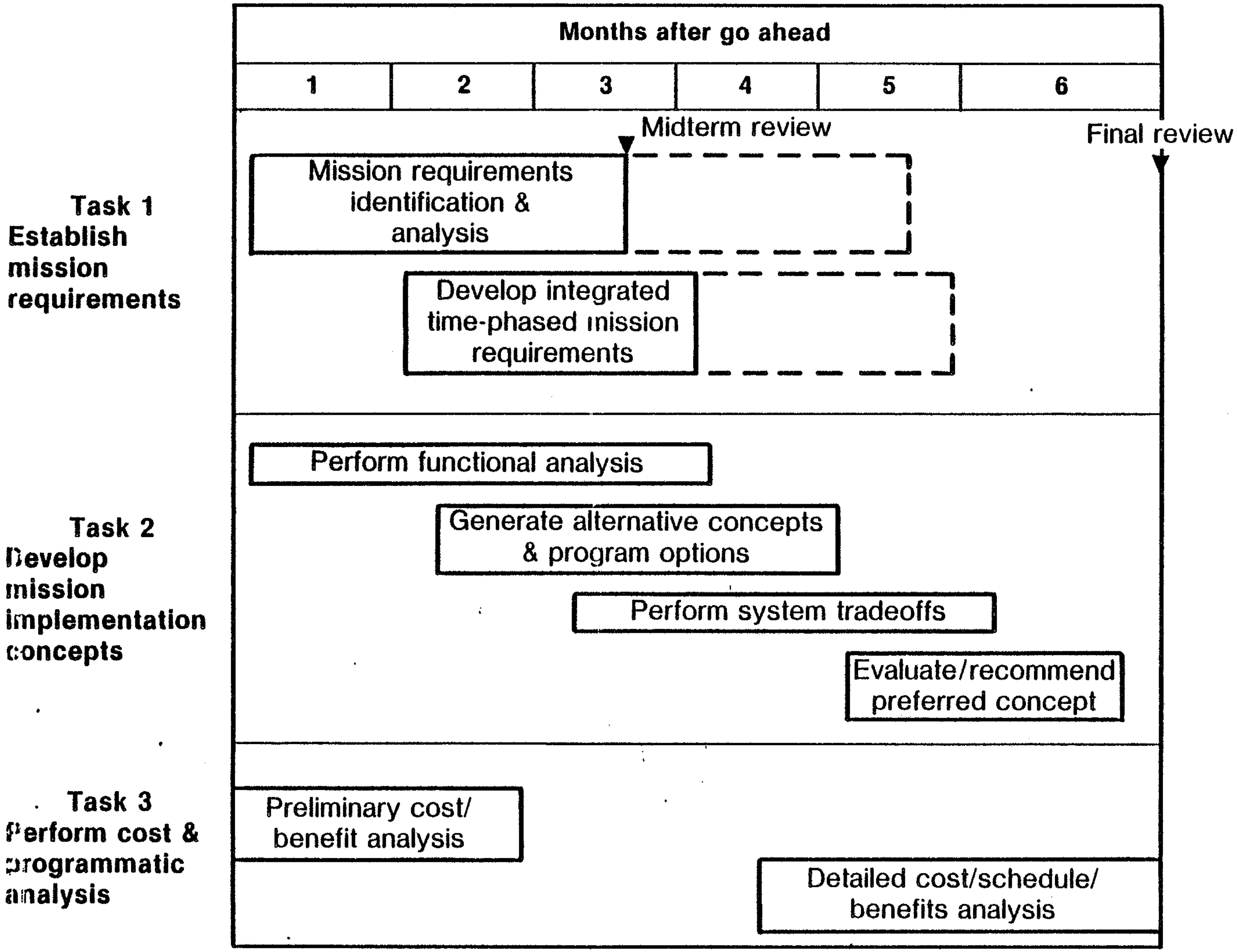
- Concentrate on development of a broad spectrum of user involvement — particularly in the commercial area
- Develop operational DoD mission scenarios based on functional needs & review/iterate with broad DoD community
- Carry out mission requirements analysis independent of architectural, cost, or programmatic considerations
- Identify areas of maximum benefit from a space station & initiate in-depth analysis
- Formulate requirements into a data base appropriate for defining candidate architectural concepts, evolutionary strategies & related costs

Our study activities during the first phase closely followed the detailed study plan submitted to NASA. Task completion is essentially on schedule. The task of identification and analysis of mission requirements is largely complete; continued iterations with users, however, will take place. Development of time phased requirements is well underway and will be completed within the next month.

Preliminary evolutionary concepts to be evaluated in the next phase have been defined.

Initial cost and benefit analysis to support activities underway in the mission requirements and implementation concepts areas have been carried out.

STUDY PLAN


Months after go ahead
1
2
3
4
5
6
Midterm review
Final review
Task 1
Establish mission requirements
Mission requirements identification & analysis
Develop integrated time-phased mission requirements
Task 2
Develop mission implementation concepts
Perform functional analysis
Generate alternative concepts & program options
Perform system tradeoffs
Evaluate/recommend preferred concept
Task 3
Perform cost & programmatic analysis
Preliminary cost/ benefit analysis
Detailed cost/schedule/ benefits analysis

The approach to identification and collection of mission requirements is shown on the facing page for typical discipline areas. A "User Brochure" was used for initial contact with a very broad commercial user community. Extensive contacts (104) were made with NASA or University research personnel in the Life Science area. A data exchange agreement has been signed with ERNO representing the Spacelab consortium. National security requirements have been obtained from a DoD provided data base, and through extensive discussions with DoD personnel. Contacts have been made with communication spacecraft users, owners and operators. The NASA provided data base for the Science and Application area has been augmented by extensive discussions with involved personnel, and by an earlier established General Dynamics data base.

STUDY APPROACH
Step 1 — Identify/Collect Mission Requirements (Examples)

Commercial
- 154 companies contacted
- Data exchange in progress
- Meetings held
- Detailed discussions planned

Life science
- 104 contacts established
- Advanced Technology, Inc subcontract
- Data exchange in progress
- Discussion/ meetings held

Foreign
- Data exchange with ERNO (spacelab consortium)
- Contact established with IHI & SPAR
- Working session with ERNO planned early December
- AEG, Dornier discussions held

National security
- DoD data base
- Meetings with SAC, TAC, space systems req office
- SAI subcontract
- Detailed follow-up discussions planned

Communication satellite
- SPACECOM subcontract
- Discussions with American Satellite, COMSAT General, Fairchild

Science/ applications
- NASA data base
- Discussions JPL, MSFC, Los Alamos National Lab
- Shuttle payload definition studies
- American Physiological Society

Total requirements

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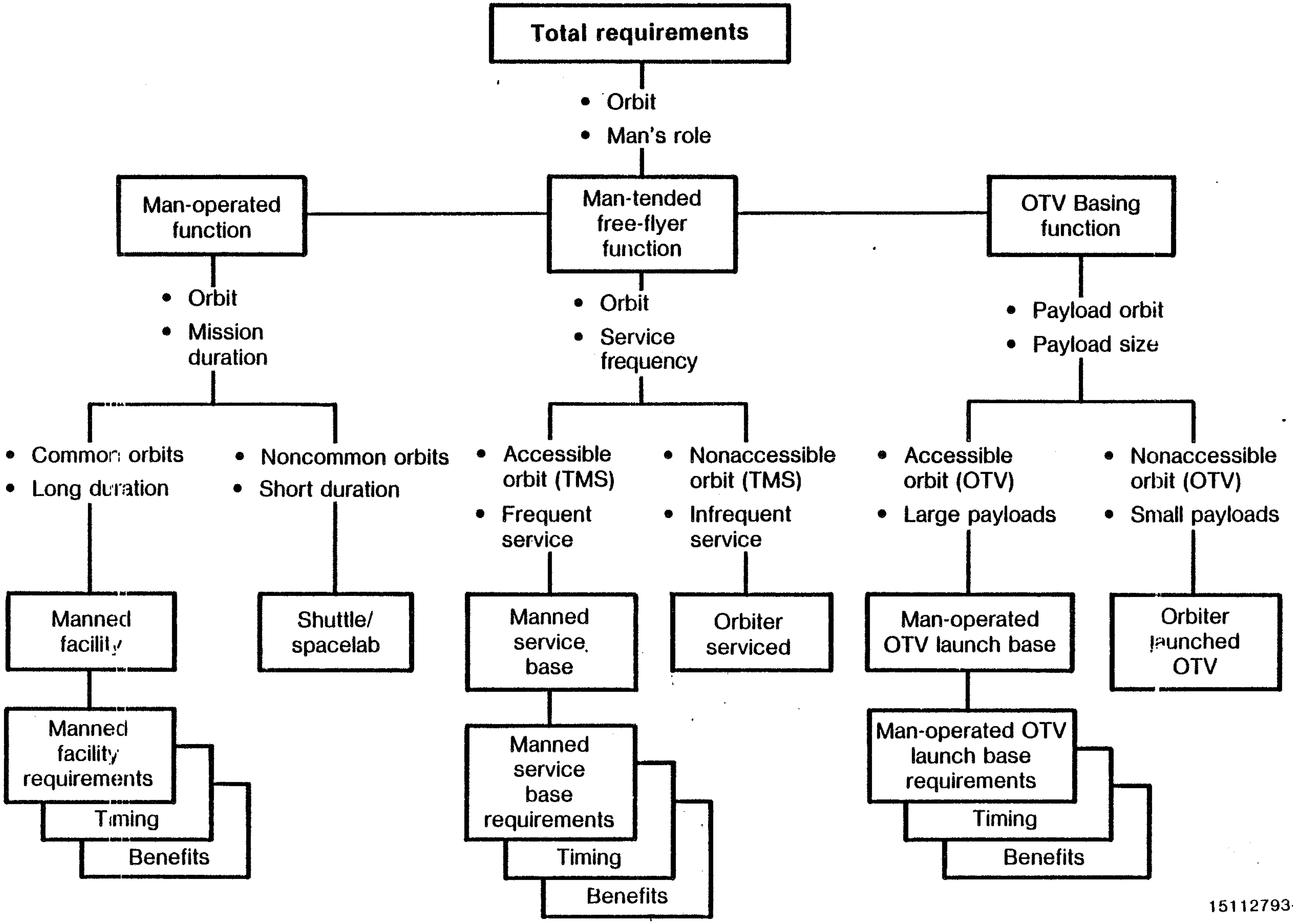
The total requirements which were collected were divided into three major functions (man-operated, man-tended, and OTV basing) using orbit requirements and man's potential role in the mission as the principal criteria for categorization. These requirements were then further subdivided into functions which would significantly benefit from a permanent presence in space (manned facility, manned service base, or man operated OTV launch base) or which could be satisfactorily performed with the existing Shuttle/Spacelab capability.

Requirements for the manned facility, manned service base, and man-operated OTV launch base were then defined and timelined. Performance and economic benefits which accrued in each area were also defined.

STUDY APPROACH (continued)
Step 2 — Characterize Requirements



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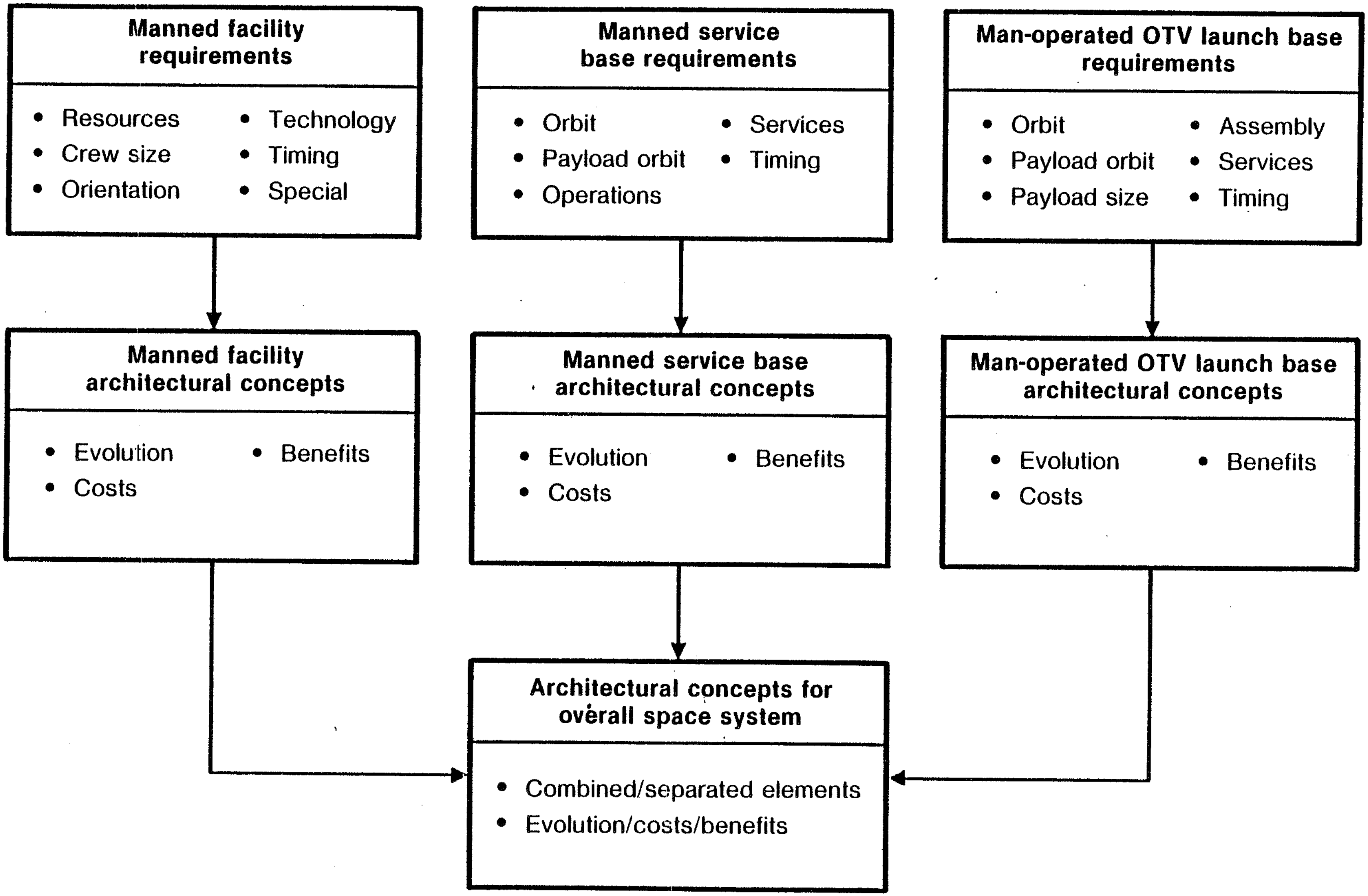
This task, which involves identification of appropriate Space Station architectural concepts and program evolutionary strategies, will be largely carried out in the second phase of our study. Architectural concepts for each of the 3 elements of the system will be defined based on requirements which have been accumulated, considering various parameters such as orbit, crew, and orientation requirements, and the level of resources (power, etc.) which must be provided to support the mission. The three system elements will then be assessed from the standpoint of whether separate or combined elements offer the greatest economic and/or performance benefits.

STUDY APPROACH (continued)
Step 3 — Perform Architectural/Cost Trades



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The missions for each of the disciplines were first cataloged and an initial appraisal made of their suitability as a Space Station candidate. Secondly, they were segregated into the three primary functions of:

Man-operated
Man-tended free flyer
OTV base

At the same time they were identified as being within the first, mid or last one-third of the 1990-2000 decade. These two listings are not presented in the review but will be part of the final study documentation.

Lastly, the time-phased charts were prepared for each of the three functional areas. These data are provided herein for each discipline. Over 160 missions were reviewed.

ANALYSIS OF INDIVIDUAL DISCIPLINES

Discipline

Astrophysics

Earth & planetary exploration

Environmental observations

Life sciences

Materials processing

Technology development

Commercial

*National security missions

⇨

Missions planned

Potential station roles

Time phasing

*Operational mission concepts developed
based on identified functions to be performed

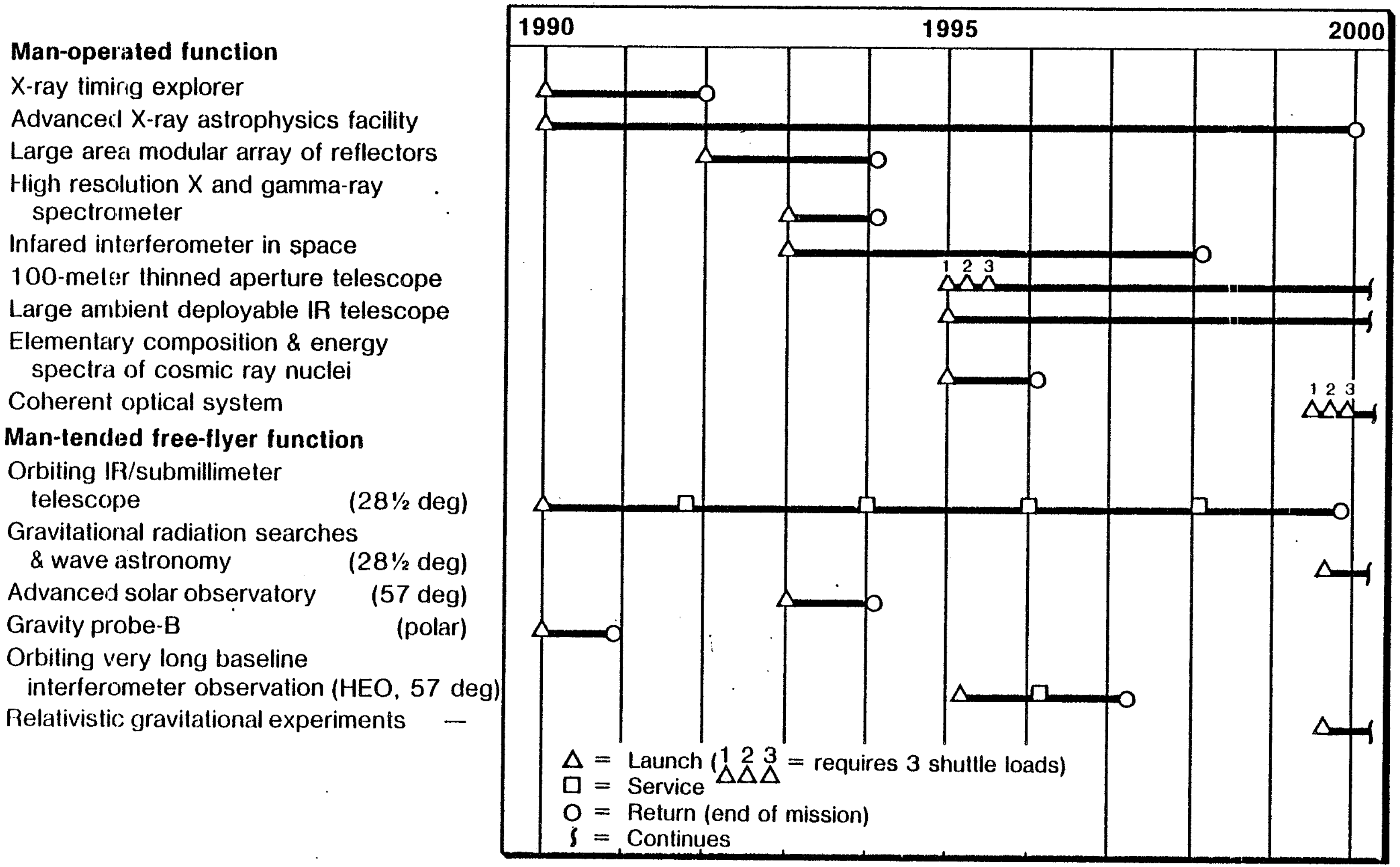
15112793-141

Many of the Astrophysics functions are facilities or observatories designed to accommodate a large number of experiments which can be included in their capability. Further, the design takes into account a myriad of guest investigators who will come to the appropriate NASA center to run their experiment. In rare cases, even, it is conceivable that the investigator could actually be sent to the Space Station to perform his experiment.

In the selection process to choose candidates that would require or whose utility would be enhanced by the Space Station, many possible vehicles were eliminated because the proposed operational time frame was before the station would be ready for use. If, as these experiments become fact, the time frame moves into the station operational era, they too would become good station residents.

MISSION REQUIREMENTS TIME PHASING

Astrophysics



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Several facts emerge from an evaluation of generic operational mission requirements. They generally require GEO or high inclination orbits and often higher than LEO altitudes. Security and survivability requirements are key and often drivers. A basic conclusion is that dedicated, i.e., not joint with scientific/foreign users, facilities are required. Some missions require multiple positions in space and are probably free-flyers. Conflicting orbit and other requirements indicate that multiple facilities are likely.

DoD RDT&E missions are derived from operational missions and directly support their evolvement when considered as two sets - R&D and T&E, logical differences are evident. Verification T&E for operational missions either require or benefit from performance in the operational environment, in this case - orbit. On the other hand, R&D missions can usually be performed under different though comparable conditions and are candidates for a low inclination LEO orbit such as that determined for S&A and commercial missions. Furthermore, the survivability requirements become progressively lower progressing from operational to R&D. Security is less demanding also but still of concern. The conclusions are, therefore, that R&D activities are suitable for a LEO low inclination orbit, even in a joint station. Some T&E missions may be also but others will require operational missions.

Because the RDT&E missions are derived from operational missions and these are not well defined at this time, the detailed technical parameters of the RDT&E missions have not been developed at this time and do not appear in our data bank like those of science, applications and technology.

DoD INFLUENCES ON EARLY STATION REQUIREMENTS

Operational missions generally require dedicated prime facilities
- High inclination/high altitude orbits
- Security & survivability are key requirements
- Availability/responsiveness/effectiveness are of high importance
- Conflict requirements set basic mission needs
- Support/training may be providable from T&E "station"

Test & evaluation missions
- Verification T&E for operational missions generally require access to same orbits (high inclination/high altitude)
- Some activities may be suitable for LEO-joint station

Research & development missions
- Suitable for early joint station in LEO
- Security aspects of concern
- Survivability not an issue
- Some missions (e.g. Earth obs, commun) similar to S&A & commercial
- Helps define requirements for operational missions

Detailed mission technical requirements not developed at this time

The data received to date is very positive from the communication satellite sector. There are strong signs of interest in MPS and more limited in the earth/ocean observations sectors. We feel that although present planning is somewhat inhibited by the perceived barriers, a stronger reason for the limited interests may be due to the basic nature of businesses. For example, if one had conducted a similar study in 1885 or even 1903 about the planned uses for the new transportation system called airplanes, a similar result would have been obtained.

We feel the potential market exists and can be developed, but it will take additional time. Furthermore, once a Space Station is in being, the activities therein will generate uses and users that are not or cannot be forseen at this time.

COMMERCIAL APPLICATIONS
Preliminary Conclusions

Communication satellite placement market exists
- OTV an economic alternative to current launch systems

Commercial communications satellite servicing a viable mission

MPS & Earth observation markets exist but need development
- Planning somewhat inhibited by perceived barriers
  - Relatively long ROI horizons
  - Space station some distance in future
  - Space operations are costly

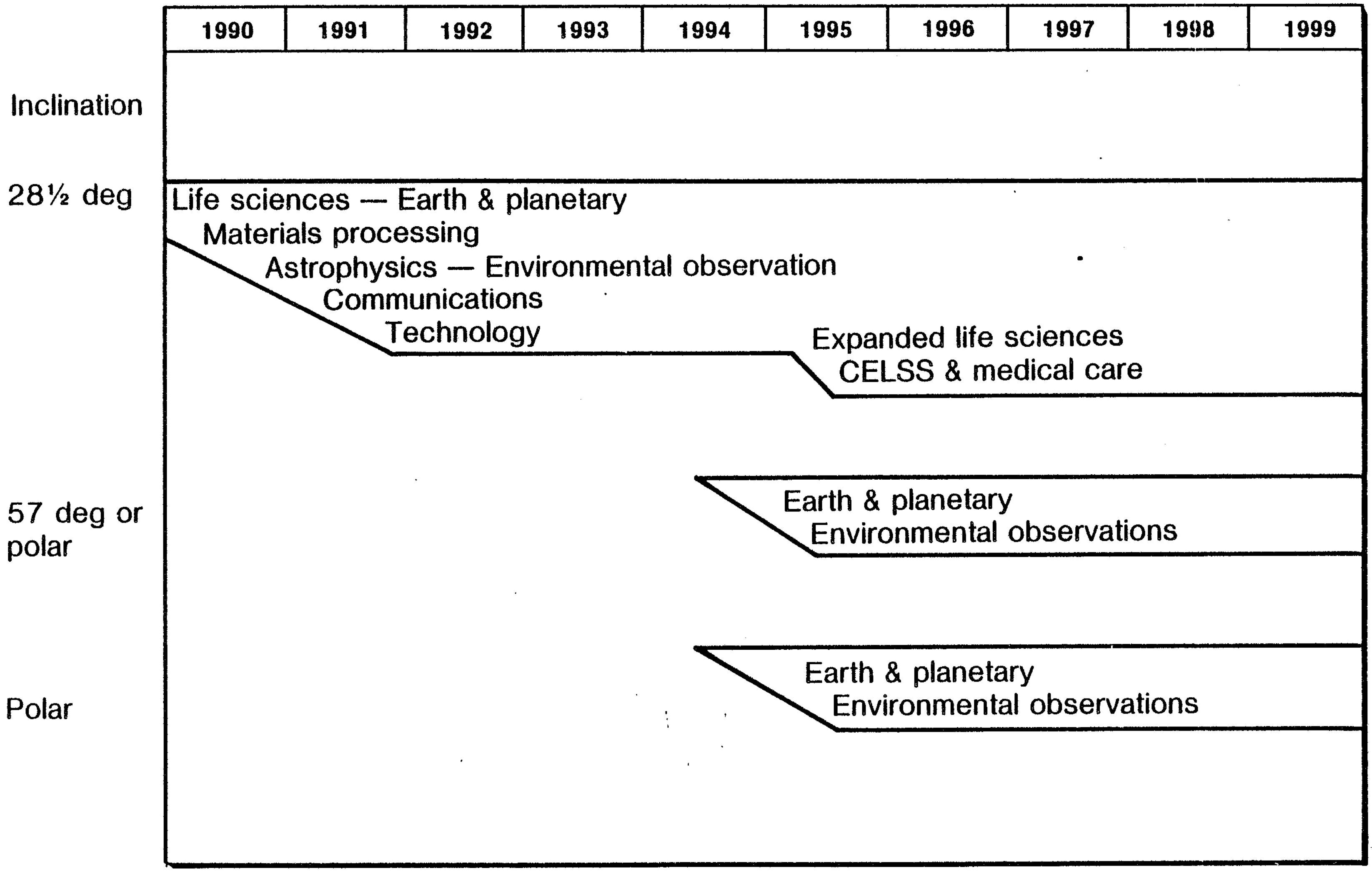
Market potential & interests exist
- Additional time & detailed discussions required to expand beyond currently identified level
- An in-place facility will generate uses that may not surface during advanced appraisals

Special incentives may be required to induce commercial firms to increase research investments

The time-phased requirements for man-operated missions to a large degree are related to orbit inclination. The earliest requirements are missions that are satisfied with a 28.5° inclination LEO. These comprise research and development missions in low "g", and viewing from above the earth's atmosphere. Other missions such as Earth-Planetary and Environmental Observation missions are projected as starting at this inclination for early development, and being relocated on a higher (57°) inclination or polar orbit when such capability becomes available. The missions requiring a 57° inclination or the preferred polar orbit appear to focus on a start by the mid-90's. The polar orbit requirement, which would likely satisfy most or all 57° missions, is seen as also required no earlier than the mid-90's.

The choice to use the 57° or polar orbits lies with consideration of ETR vs WTR launch availability and the comparative payload delivery capability of the Shuttle from these two locations.

MAN-OPERATED FUNCTION
Time Phasing of Requirements



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The time-phasing of the OTV basing function requirements is dependent on several major considerations, including transition from current or planned upper stages - PAM, IUS and Centaur - to the re-usable OTV. A parallel consideration is the design of spacecraft for compatibility with the OTV. Another major consideration is the projected increase in both launch rate and spacecraft size.

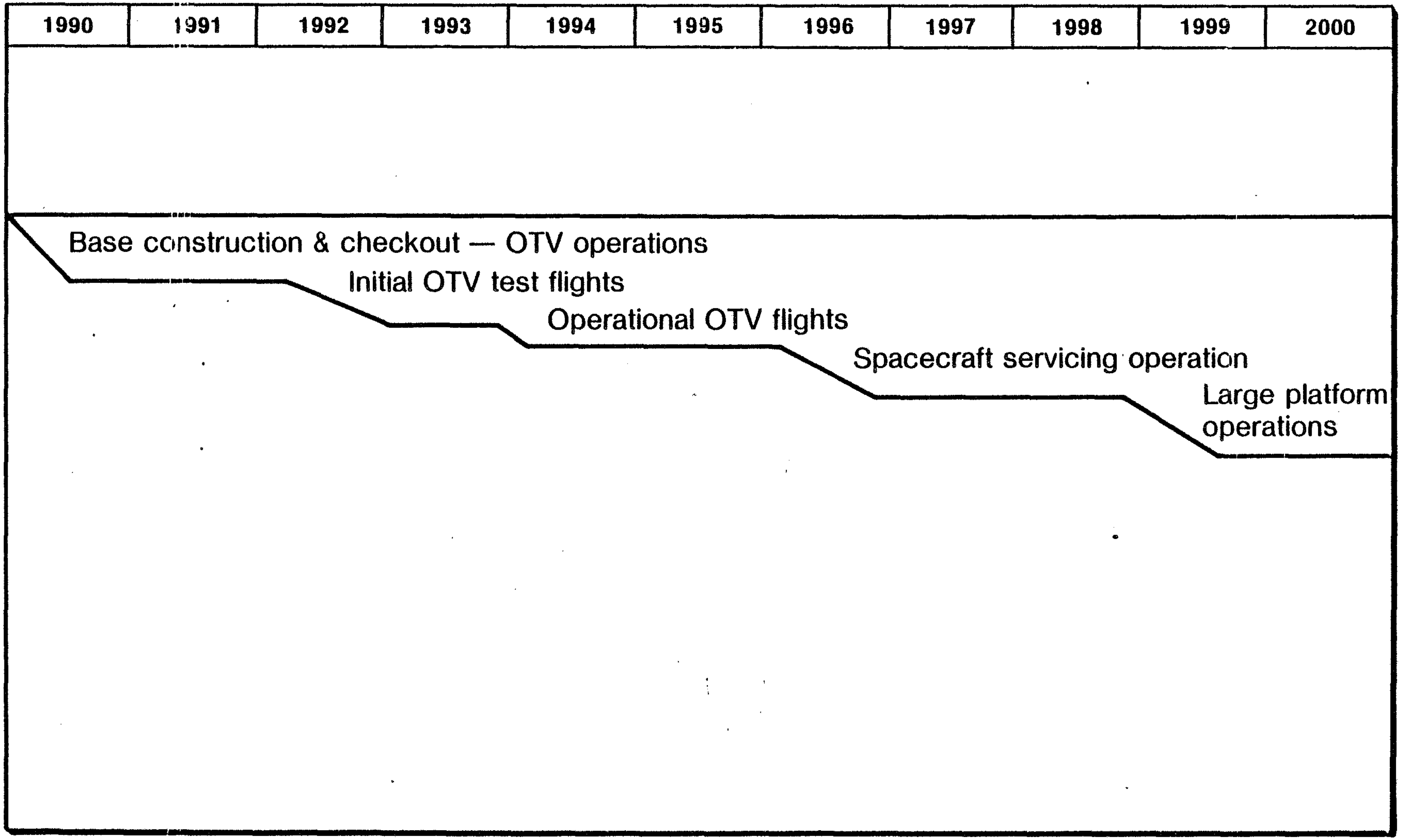
For the case of the transition to re-usable OTV taking place in the early part of the 1990's the following time-phasing of requirements applies:

- Spacecraft servicing and checkout resources are required starting with the initial spacecraft delivery using the operational OTV. Resources to support servicing of spacecraft at GEO - or by return to LEO - are required by the following two or three years.

- Final years of the decade require the capability to assemble and launch very large platforms containing either large antennae, or multiple spacecraft.

- OTV base construction, checkout and test flights need to be completed in time to support the transition to the operational space-based OTV.

OTV BASING FUNCTION
Time Phasing of Requirements



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The accommodations necessary to meet mission requirements for the initial phase of the Space Station includes a basic capability in LEO 28.5° inclination to house mission equipment, and provide resources - crew habitat, power, and station support systems for the early year missions.

Summation of free-flyers operating in a wide range of orbits shows a need to accommodate servicing capabilities and resources for about 4 free-flyers. These free-flyers will be added to those existing in orbit in 1990, which if so designed, could also be accommodated by Space Station servicing, e.g., Leasecraft.

An OTV basing capability is required to coincide with OTV operational capability, to service and launch approximately 2 to 3 DoD satellites per year plus 1 to 2 communication satellites and planetary missions.

SUMMARY OF MISSIONS — INITIAL REQUIREMENTS (1990/1991)

Man-operated 28½°
400-500 km

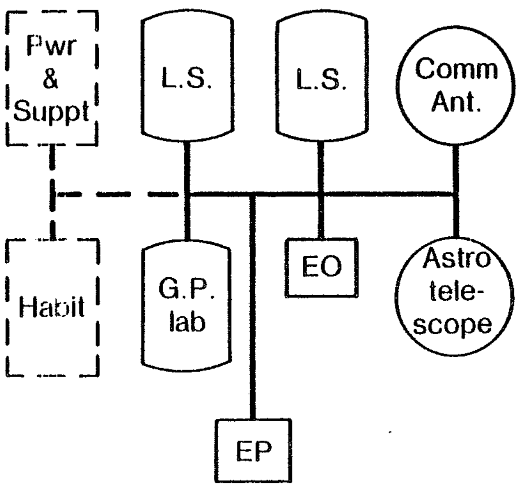
2 modules — life sciences
1 general purpose module
1 communications antenna
1 astro telescope
1 env obs pallet — 4m × 10m
1 earth plan pallet — 4m × 6m
  4 to 6 P/L crew
~20 kw avg
(DoD-R&D can be accommodated)

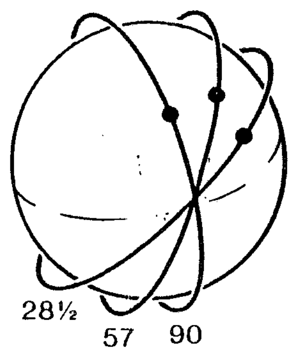
Man-tended free flyers
LEO

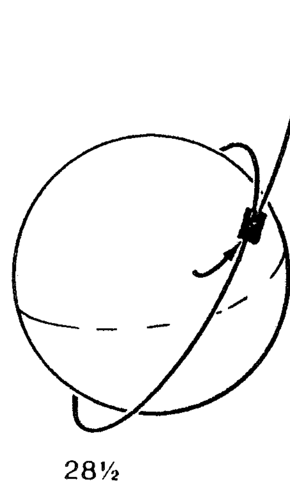
1 astrophys — 28½°
1 MTLS pro — 28½°
1 earth obs — 57°
1 earth obs — 90°
(DoD not shown)

OTV basing

1 to 2 commun sat./yr — GEO
1 planetary sat./yr — ESC
1 Earth obs — HEO
2 to 3 nat'l sec sat./yr







The accommodations for the mission equipment required for the initial phase will require expansion in all areas of operation to accommodate an expanded set of missions.

The Man-Operated Function missions are augmented by increased Life Sciences research, Environmental Observations and addition of major Earth and Planetary mission equipment. Mission requirements in Astrophysics increase to accommodate additional telescopes. Communication and Technology Development are expected to continue from the initial phase, requiring capability to assemble and operate much larger elements.

The quantity of free-flyers increases to 1 to 2 spacecraft in each orbit inclination, potentially using LEO platforms where warranted to group sensors and share services.

The OTV Basing Function grows to meet launch and service requirements for 8 DoD satellites per year, 12 to 20 communication satellites to GEO each year, along with continued Planetary missions and the addition of Environmental Observation satellites to be placed at GEO.

SUMMARY OF MISSIONS — FINAL REQUIREMENTS (2000)

Man-operated 28½°
400-500 km

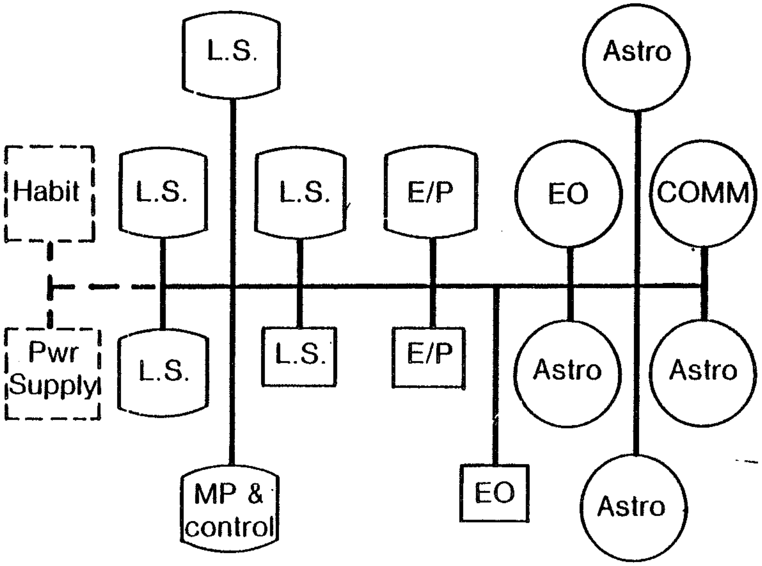
4 life science modules
1 earth/plan module
1 MP & P/L controls module
1 commun anten
4 astro telescopes
1 env obs anten
1 env obs pallet — 4m X 6m
1 earth plan pallet — 4m X 20m
1 life science pallet
10 to 12 P/L crew
60 to 80 kw avg
(DoD-R&D can be accommodated)

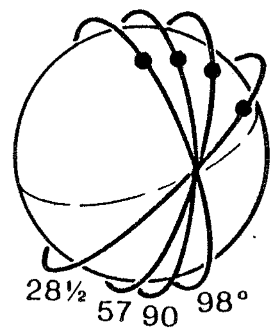
Man-tended free flyers
LEO

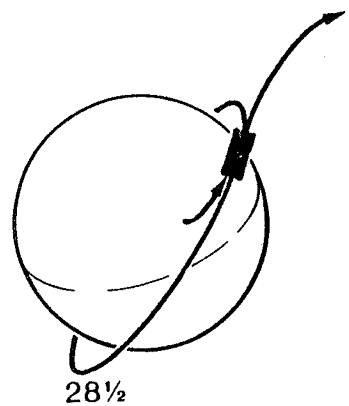
1–2 astrophys 28½°
1 mtl proc 28½°
1–2 env obs 57°
1–2 env obs 90°
2 env obs 98°
(DoD not shown)

OTV basing

12 to 20 commun sat./yr — GEO
1 weather sat. (set) — GEO
1 planetary sat./yr — ESC
1 Earth obs — HEO
9 nat'l sec sat./yr







Major benefits are indicated that are directly attributable to having man in orbit for extended time periods for the conduct of research, and for development of advanced technologies. These benefits will be realized in both low "g" research, and viewing Communications and Technology experiments missions.

Man's tending of free-flyers, either from a Shuttle or from space-based systems, provides benefits in quality of observations, and in extending the useful life of observatories.

Benefits of a performance nature resulting from OTV basing are primarily due to man's capabilities for on-orbit checkout and servicing of spacecraft prior to commitment to HEO and GEO missions. At later dates additional benefits may accrue from servicing of GEO spacecraft by man at LEO or by automated means at GEO.

SUMMARY OF PERFORMANCE BENEFITS

Function	Potential Benefit	Disciplines/Missions
Man-operated	• Scientific research requiring man's presence for periods exceeding 12 to 14 days	Life Sciences
	• Advanced technology development requiring man's presence over extended mission times	Communications Earth/planetary Env observations Materials processing
	• Assembly and servicing of large observatories in LEO	Astrophysics
Man-tended free flyers	• Increased quality of observations by on-orbit servicing of sensors & spacecraft	Astrophysics Envir observations
	• Increased useful life of observatories by update/changeout of sensors, replenish consumables	Astrophysics
OTV basing	• Increased quality & reliability of spacecraft systems by checkout, servicing and deployment, prior to commitment to GEO	Communication Planetary Envir observations
	• Increase in technical performance of spacecraft by on-orbit assembly & checkout in LEO of multi-shuttle flight systems	Environ observations

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Man-Operated Function

- Permanent basing of Spacelab-type module at LEO Space Station eliminates need for Shuttle launch of Spacelab. Launch and LEO integration of replacement experiments and supplies should cost only about one-third of typical Shuttle-Spacelab mission, due primarily to reduced cargo bay use and Shuttle time-on-orbit. Savings per typical one-week equivalent Spacelab mission are conservatively estimated at $50 million.
- Reduction of time required for commercialization of applications research, particularly in materials processing in space, should result from continuous laboratory operations. Economic benefits to be determined.
- Technology development and life science advancements should yield as yet unquantified economic returns.

Servicing of LEO Free-Flyers

- LEO-basing of TMS will save a minimum of $5 million in Shuttle transportation costs per TMS mission. Hydrazine propellant for TMS is assumed to cost $1500/lb for delivery to LEO.
- Reduction of Shuttle time-on-orbit will result from space-basing of servicing operations.
- Extension of operating life of LEO assets could provide annual benefits of tens of millions of dollars.

Space-Based OTV

- Greatest economic benefit of Space Station appears to be reduction in launch costs to high orbits with a reusable space-based OTV. SB OTV operating costs are estimated to be 20-50% lower than Shuttle-Centaur, depending on cost of propellant delivery to LEO. Detailed analysis of OTV costs is presented in costs and programmatics section.
- Sale of propellant recovered from ET during standard Shuttle missions can generate additional revenue and cost-reduction opportunities for all Shuttle users. Nominal estimates of 28,000 lb of propellant recovered and sold to OTV users at $250/lb yields benefit of $7 million per Shuttle flight.
- Based on projected cost per transponder-year over $250,000, among other factors, servicing of geo-synchronous communications satellites and other high-orbital assets should provide great economic benefits, to be determined.

SUMMARY OF SPACE STATION ECONOMIC BENEFITS
Preliminary Analysis

	Number of Missions (annual)	Benefit per Mission	Total Annual Benefit	Primary* Beneficiaries
I. Man-operated function				
• Reduction in spacelab module carrying charges	6	$50M	$300M	S
• Reduction in time required for commercialization of R&D processes	TBD	TBD	TBD	S,C
• Technology development & life science advancements	TBD	TBD	TBD	S,C
II. Servicing of LEO free-flyers				
• Reduced TMS carrying charges	15	$5M	$75M	S,D
• Reduction in shuttle time-on-orbit	TBD	TBD	TBD	S,D
• Extension of operating life of LEO assets	TBD	TBD	TBD	S,D
III. Space-based OTV				
• Reduction in payload launch costs to HEO/GEO	15	$54M	$815M	C,D
• Shuttle-user benefits from ET propellant recovery	24	$7M	$168M	S,C,D
• Extension of operating life of HEO/GEO assets	TBD	TBD	TBD	S,C,D
Totals	60 +	$22.6M (Average)	$1360M +	

Conclusion: Identified net economic benefits to space station users exceed $1.3 BILLION annually. Economic benefits TBD could raise this figure significantly.

*Primary beneficiaries: S = Science & applications C = Commercial D = Defense

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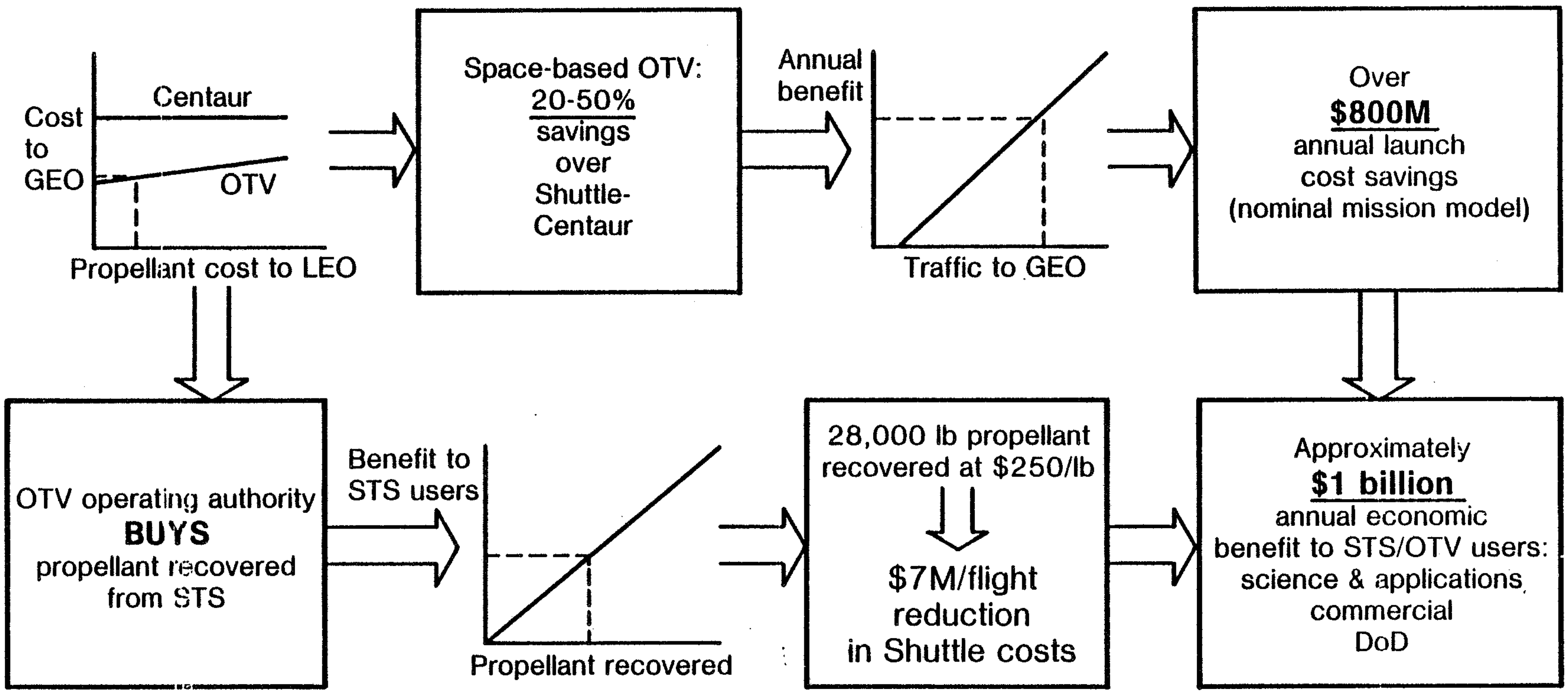
Flow-chart provides overview of a space transportation scenario which may be a key economic justification for the establishment of a Space Station. Permanent basing of a re-usable Orbital Transfer Vehicle (OTV) at a Space Station offers a potential $800 Million reduction in the annual cost of delivering payloads to Geosynchronous orbit, based on a comparison with the SBOTV's closest competitor, the Shuttle-Centaur.

An additional benefit can be realized if propellant is recovered from the Shuttle's external fuel tank; NASA could sell this propellant to OTV users (perhaps via an "OTV Operating Authority") and generate revenue to help defray Shuttle operating costs. Recovery of 28,000 lb of propellant per flight, and sale of this fuel to OTV users at $250/lb, offers a potential $7 Million reduction in the Shuttle cost-per-flight, a benefit to all users of the Space Transportation System. Total annual economic benefit from the SBOTV could approach $1 Billion, not counting the benefits of satellite checkout and servicing.

HOW TO PAY FOR A SPACE STATION
Efficiency in Space Transportation
A Summary of Space Station Economic Benefits



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Three program evolutionary options have been defined for further investigation during the second phase of this study. Each of these options, as characterized on the facing page, will be evaluated considering economic, performance, programmatic, and political implications. As a final step, a preferred option will be identified and substantiated.

PRELIMINARY SPACE STATION PROGRAM EVOLUTIONARY OPTIONS
General Characteristics

Option 1	Option 2	Option 3
Manned Station 1 Function: Science/applications, commercial, technology Assumed IOC: 1990/1991	**Manned Station 1** Function: OTV/TMS/servicing Assumed IOC: 1990/1991	**Interim Manned Station** Function: Limited science application, commercial, technology Assumed IOC: 1990/1991
Manned Station 2 Function: OTV/TMS/servicing Assumed IOC: 1993/1994	**Manned Station 2** Function: Science/applications, commercial Assumed IOC: 1994/1995	**Advanced Manned Station 1** Function: OTV/TMS/servicing Assumed IOC: 1995
DoD Manned Station Function: Operational DoD missions Assumed IOC: 1994/1995	**DoD Manned Station** Function: R&D/operational DoD missions Assumed IOC: 1990/1991	**Advanced Manned Station 2** Function: Science/application, commercial, technology Assumed IOC: 1997

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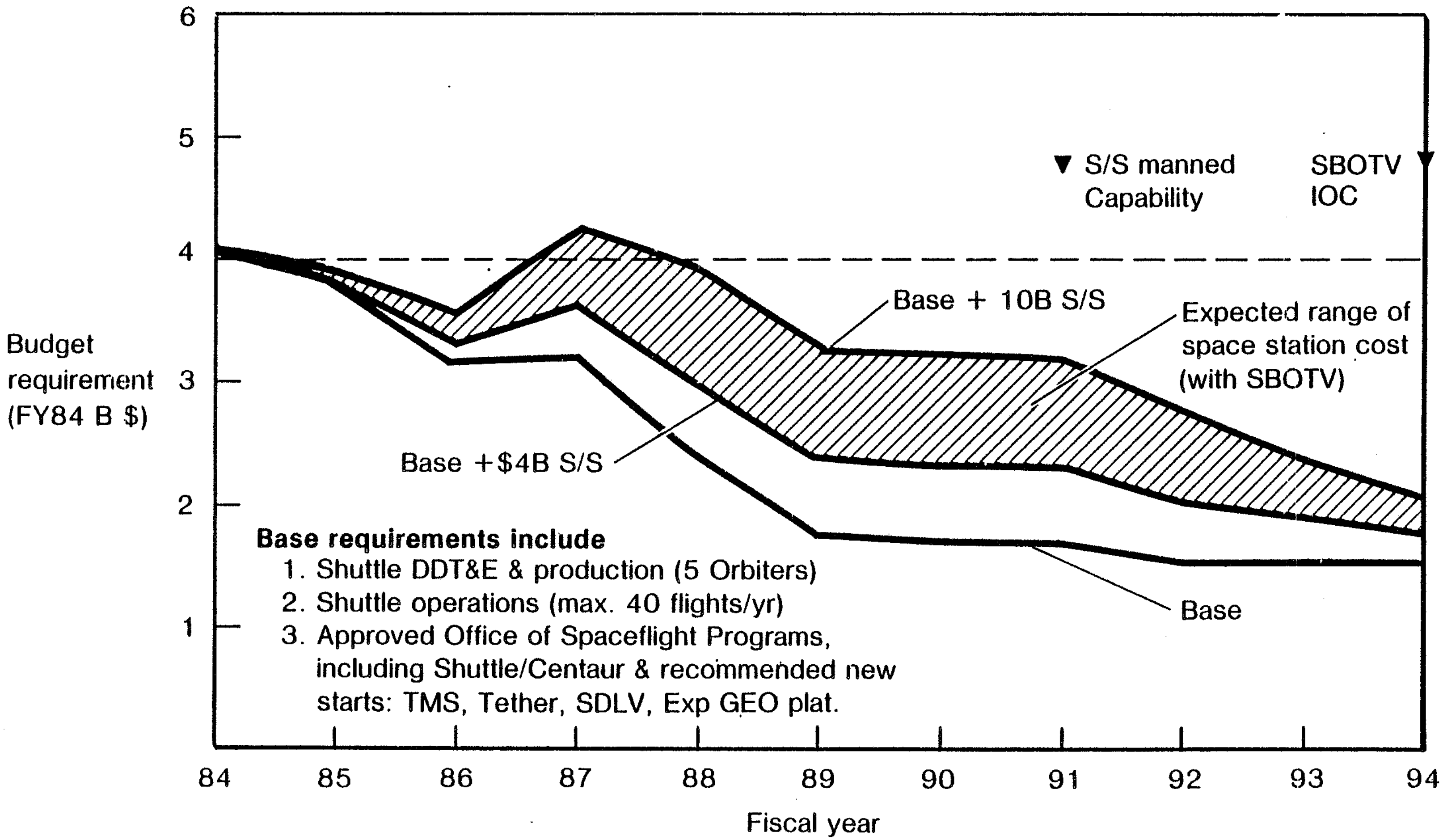
Projected run-out of NASA Office of Spaceflight programs, including completion of DDT&E on 5-Orbiter Shuttle fleet and non-reimbursable Shuttle operations costs through 1994 (maximum 40 flights per year). Also included in base are ongoing programs in Space Transportation, such as Advanced Planning and Engineering/Technology Development, plus four potential new starts: Teleoperator Maneuvering System, Tethered Satellite, Shuttle-Derived Launch Vehicle, and Experimental Geostationary Platform. Shaded area shows impact of a Space Station program on budget requirements, ranging from a $4 billion Space Station program (lower bound of shaded region) to a $10 billion program (upper bound). The $4-10 billion range represents roughly the non-recurring cost range for a Space Station with an operational space-based OTV capability.

IMPACT OF SPACE STATION ON NASA SPACE TRANSPORTATION BUDGET REQUIREMENTS



1512793-49

The General Dynamics study clearly indicates that extensive requirements do exist which support the need for a Space Station, and that the station will provide significant economic and performance benefits to presently planned missions. Our study shows that an OTV base provides the most significant and quantifiable economic benefits. This aspect will be more extensively studied in the next phase of the study.

Commercial interest in a Space Station has been identified and developed in a number of areas. We expect that this interest can be more extensively developed over a period of time through continued interaction with the user community.

Our studies indicate that joint NASA/DoD use of an early Space Station for R&D and T&E missions would be of benefit to both parties. Preliminary studies also indicate that a separate station for operational DoD missions may be necessary; this aspect however requires further study.

MAJOR STUDY CONCLUSIONS

- A space station will provide major performance & economic benefits to a wide range of missions planned for the early 1990s
- Development of a man-operated OTV base provides the most significant & the most quantifiable economic benefits
- Economic benefits quantified to-date exceed $1.3 billion per year, offering potential for rapid payback of space station investment
- Combined NASA/DoD utilization of an initial space station provides economic & technical benefits — preliminary studies of operational missions indicate need for a separate station(s)

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SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS
Midterm Briefing

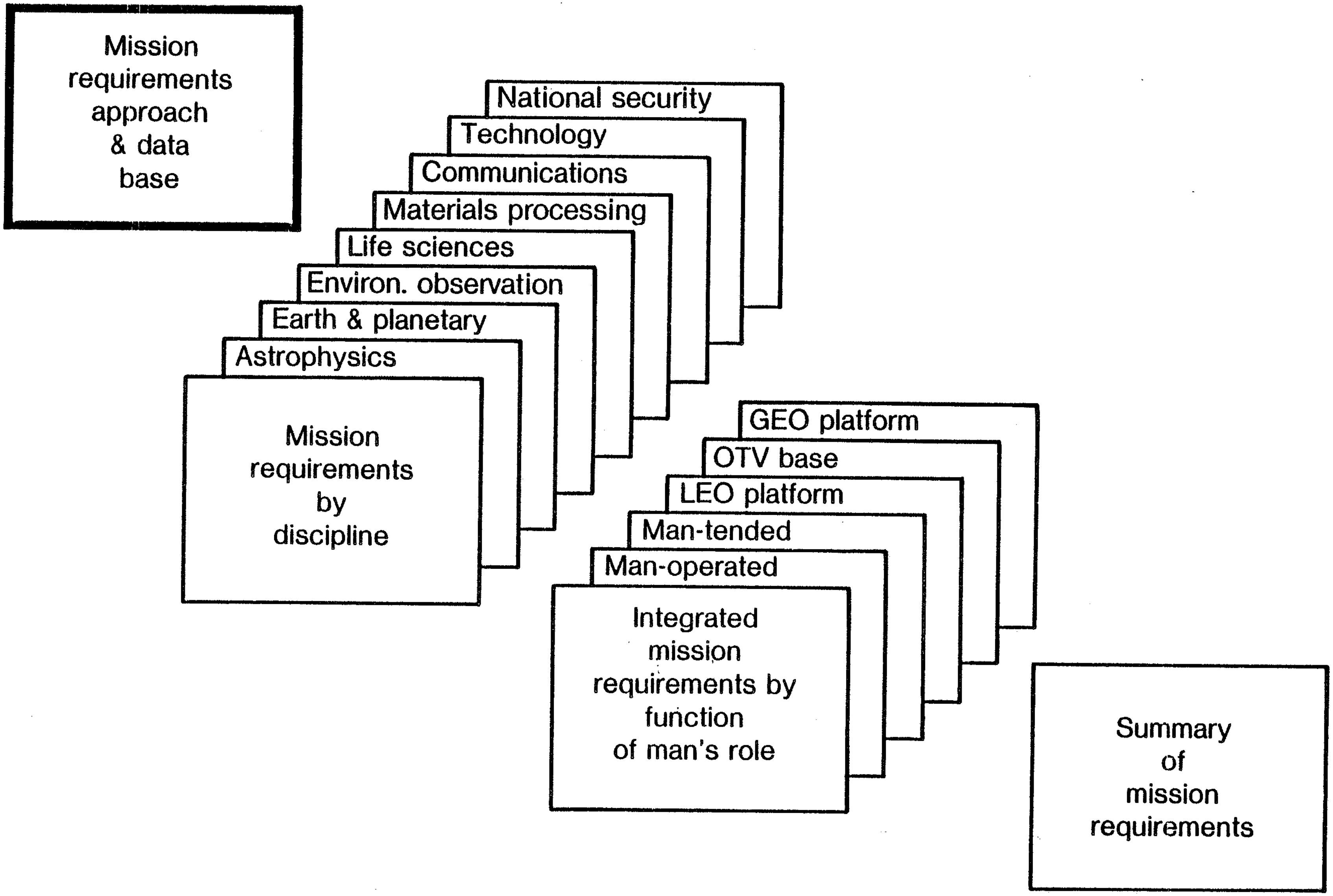
	Presenter
Introduction	Don Charhut
Executive Summary	Otto Steinbronn
Mission Requirements	Warren Hardy/Dick Norris
Approach & Data Base	
Mission Requirements	
Integrated Mission Requirements	
Summary of Mission Requirements	
Mission Implementation	John Bodle
Cost & Programmatic Analysis	Bob Bradley
Summary	Otto Steinbronn

15112973-3

The mission requirements presentation is divided into four sections:

1. Approach and Data Base
2. Mission Requirements - arranged by discipline
3. Integrated Mission Requirements - arranged in accordance with man's involvement
4. Summary

Our study approach was described earlier in the Executive Summary. This section contains a brief reminder of the approach we used in analyzing mission requirements. There is also a description of our data base and the validation of the data.


Mission requirements approach & data base
National security
Technology
Communications
Materials processing
Life sciences
Environ. observation
Earth & planetary
Astrophysics
Mission requirements by discipline
GEO platform
OTV base
LEO platform
Man-tended
Man-operated
Integrated mission requirements by function of man's role
Summary of mission requirements

15112793-53

The mission and payload requirements received from a variety of sources were documented using the LaRC developed format. As these were collated and assessed for completeness, it became apparent that some technical parameters were missing and many - especially those of science and applications - had been structured without a manned Space Station in mind. The data were expanded and completed as necessary and the role of man appraised to determine where he could enhance or contribute to the mission.

The missions were then segregated by orbit inclination/altitude and into three basic functional categories:

Man-Operated
Man-Tended Free Flyers
OTV Supported

From a requirements viewpoint, it was better to treat these as three separate functions without regard to how they might be implemented by physical configurations. It was understood that man-operated implied a manned laboratory type station with internally and externally mounted experiment/payload equipment. Also, that the free-flyers were separate entities which were supported for service, maintenance and possibly operations from a manned facility.

The requirements for the three functions were collected and evaluated to determine the aggregate station resource requirements. No time lines were created due to the scope of the effort. It is apparent that considerable work remains to be done in this area. However, the range of values for the key parameters is reasonable and of sufficient accuracy for the architectural option studies and evaluation.

MISSION REQUIREMENTS APPROACH

Collect mission requirements →

- NASA provided
- NASA center visits
- Commercial contacts
- Univ contacts/visits
- DoD inputs
- DoD visits
- Previous studies

Assess/ collate inputs →

Expand as required →

Segregate by orbit & man's role →

- Man-operated LEO
- Man-tended LEO
  - Free flyer
  - Service function
- Man-launched/tended HEO
  - Free flyer
  - Boost function
  - Service function

→ **Define requirements by functional element** →

- Manned lab
- Free-flyer service base
- OTV base
- LEO platform
- GEO Platform

Summarize & total requirements of of key parameters

- By functional element
- Time phased

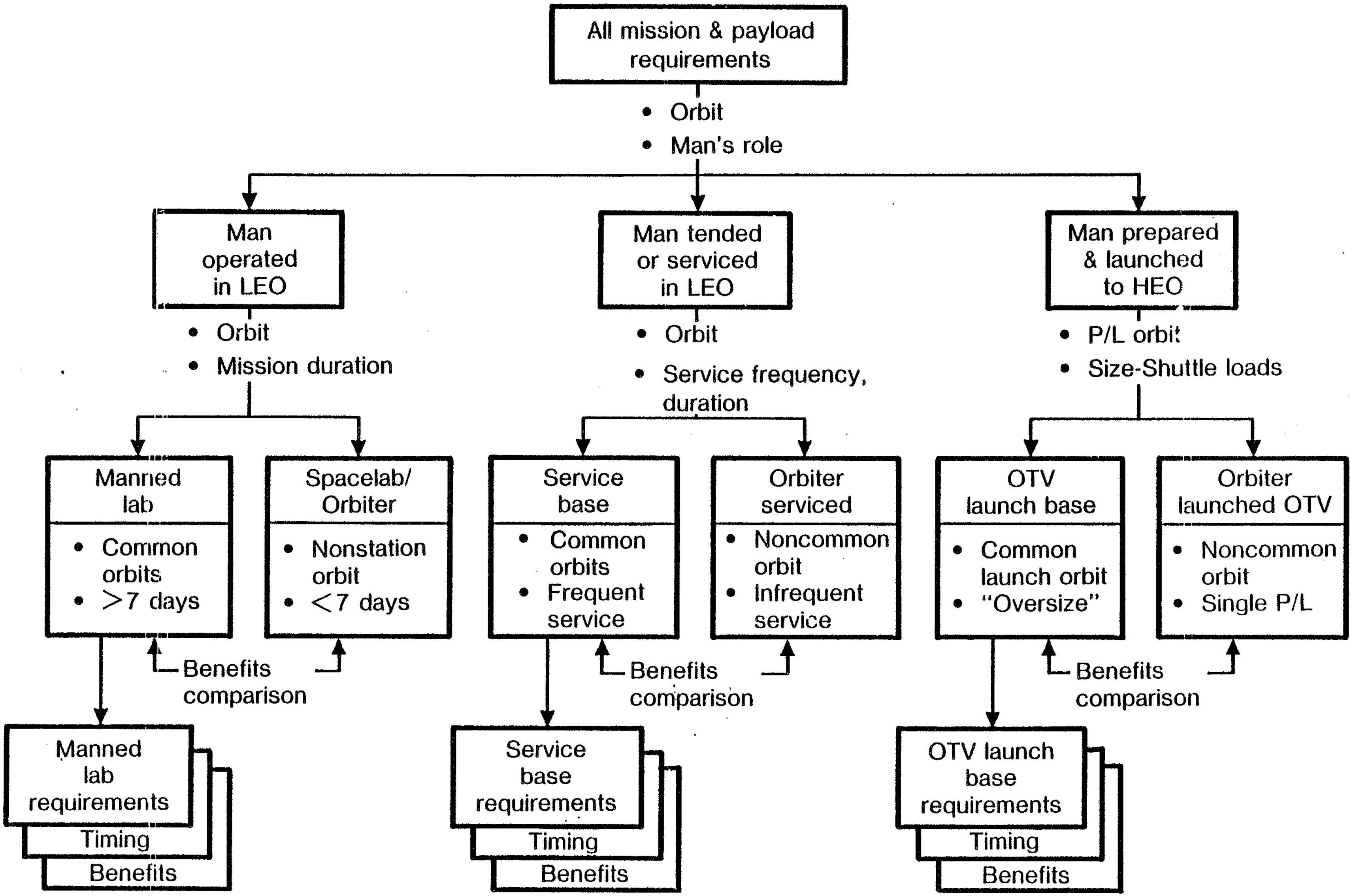
15112793-16

These are the successive steps of the segragation analysis. First by orbit and man's role in terms of the three primary functions. Then for each of the functions, an evaluation was made of how well existing STS elements could satisfy the requirements. Again, orbit considerations are important as well as time in orbit or frequency of involvement, e.g. for servicing.

Even when the Shuttle/Spacelab could perform the mission, a benefits analysis may determine that for cost or performance reasons, the mission should be accomplished on a Space Station.

The mission requirements were then aggregated by function and a judgment made of the station resource capability to be provided.

REQUIREMENTS SEGREGATION



15112793-15

The mission requirements for a manned Space Station were compiled from a combination of NASA and DoD study reports, personal visits to many facilities, telephone contacts to industry with questionnaire follow-ups, and information compiled by subcontractors.

The mission analysis study orientation briefing of 15 September 1982 was used as the basis for many user requirements. A number of additional reports such as the CELSS program plan of April 1982 and the MSFC Mission Model, Revision 6, were used to expand the requirements definitions in areas such as life support and communications. DoD study reports such as the Military Space Station Security Study of 1 April 1982 and the Military Space Station Study of June 1982 were used as for National Security Missions.

Visits were made to various NASA and DoD centers, including NASA headquarters, ARC, JPL, JSC, MSFC, and DoD visits at SAC, SD-JSC, and TAC.

The Space Station User Brochure resulted in a number of discussions describing commercial and scientific requirements, and additional user source data was received from GDC subcontractors.

USER SOURCES

- **Mission Analysis Study Orientation Briefing, 15 September 1982**
- **Previous NASA study reports** (examples)
  - Space Platform Payload Data, March 1982
  - Space Operations Center Program Plan, November 1981
  - CELSS Program Plan, April 1982
  - Astrophysics Near-term Program Project Concept Study, October 1980
  - MSFC Mission Model, Revision 6
- **Previous DoD study reports** (examples)
  - Military Space Station Security Study, 1 April 1982
  - Military Space Station Study, June 1982
- **NASA Center visits & discussions**
  - HQ, ARC, JPL, JSC, MSFC
- **DoD Headquarters visits**
  - SAC, SD-JSC, TAC
- **University visits, discussions & user brochure inputs**
- **Commercial industry discussions & user brochure inputs**
- **General Dynamics Convair subcontracts**
  - Advanced Technology, Inc.
  - Science Applications, Inc.
  - Spacecom Co.

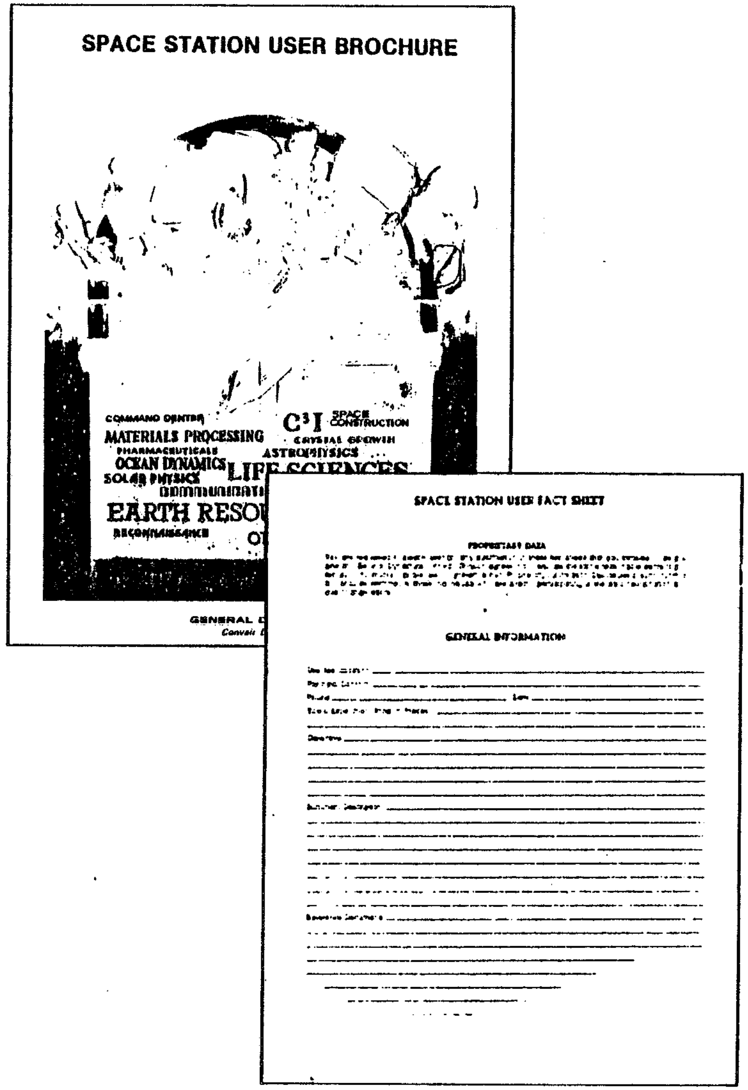
15112793-119

A Space Station User Brochure was developed by General Dynamics Convair Division to convey to potential users the opportunities and attributes of a manned Space Station. The brochure detailed the potential technological and economic benefits of such a station plus offering a concise summary of America's current and planned space activities.

Enclosed with the brochure is a "User Fact Sheet", designed so the user can reply with an indication of their economic interest, as well as a technical definition of their potential needs in terms of size, weight, orbit, crew requirements, etc. The sheet was structured so the recipient can respond by simply checking the applicable answers, with additional space provided for more detailed answers if they wish.

The brochures were offered after personal contacts were made with potential users from industry, utilities, universities, research institutes, NASA centers, and foreign sources. More than 250 brochure have been distributed, and to date more than 40 replies have been received. All replies are acknowledged with a letter to the user thanking him for his time and effort and telling him that he will be kept informed of future space developments.

USER CONTACTS



User brochure
- Station opportunities, attributes & STS financial data

User fact sheets
- Economic & planning factors
- Technical factors — e.g. orbit, crew, power

Personal contacts & mailings
- 149 industrial firms/labs
- 6 utilities
- 104 universities
- 3 biological research institutes
- 5 NASA centers
- foreign (by ERNO-MBB)

Replies to date
- 30 industrial firms
- 2 utilities
- 12 universities

15112793-17

The Space Station potential for commercial users includes both the user of station space or services, as well as the provider of equipment and operations. The list of candidates for participation started with those firms who had participated in the NASA/corporate associates program - approximately 145 firms. This list was augmented by additional firms listed in Fortune's top 500 with industry sales in metals and non-metals, chemicals, pharmaceuticals, equipment, petroleum, foods, mining and forestry, communications, aerospace, electronics, instruments and utilities.

About 180 telephone contacts were made with key department personnel in the selected firms. Almost all of those contacted expressed an interest in receiving more information of the Space Station program. Of the approximately 150 commercial firms contacted, we estimated that fewer than one-fourth were likely candidates as Space Station users. The balance were interested in drawing upon the technology to be developed. After the brochures were sent, 32 firms responded with either the fact sheet or letter.

The categories where positive interest was shown included earth and ocean observations, material processing, and communications. Most firms found the Space Station lead time beyond their present corporate planning timetable, and could only respond in generalities. It is also apparent that their interest will increase as the program comes closer to reality.

COMMERCIAL USER CONTACTS

NASA/AIAA Corporate Associates Program Listing (145) — augmented by additional firms from Fortune Top 500

- Metals & nonmetals
- Chemicals
- Pharmaceuticals
- Equipment
- Petroleum
- Foods & forestry
- Communications
- Aerospace
- Electronics
- Instruments
- Utilities

Telephone contacts made	180
• Affirmative responses	155
• Number of brochures mailed	182
Responses	32
• No interest	15
• Low interest	4
• Moderate interest	6
• High interest	7
Categories of positive responses	
• Earth & ocean observation	2
• Materials processing	6
• Communications	1
• General	3

15112793-19

ERNO, in their lead role for the Spacelab consortium, is conducting a review of European firms to identify potential users. We have a memorandum of agreement with them that includes a provision for them to share with us the results of their appraisals. We have received our first input from ERNO which provides general statements and trends in three areas:

Materials Processing
Life Science
Operations Support

Additional information to be made available following the midterm will be incorporated in the final report.

Data to be supplied from other foreign sources will be incorporated also upon its availability.

INTERNATIONAL DATA SOURCES

Current activity

- MOA established with ERNO for spacelab consortium
- Initial input data received

Anticipated at a later date

- Canadian study results
- ESA study results
- Japanese study results

The data base generated for the Space Station Study user requirements was validated by reviews with knowledgeable persons and groups in areas of Science and Applications, as well as commercial disciplines. Of the seven disciplines validated, 3 have potential in both Science & Applications and commercial fields, 3 are Science and Applications only, and one, communications, was limited to the commercial field.

The Astrophysics discipline was validated by visits to MSFC and Los Alamos National Lab. Earth and Planetary Exploration was validated in the scientific area by visits to JPL and inputs from Universities. Oil company contacts were used to validate the data in commercial applications. Environmental observations were validated by visits to MSFC and the Southern California Edison Company for commercial use. Life Sciences were discussed with numerous NASA centers, university visits, and a subcontract with Advanced Technology, Inc.

Materials Processing was validated by visits to MSFC, JPL, and a number of discussions with commercial firms. The subcontract with SAI was also used. Space Communications Co. conferred with a number of Satellite users, such as American Satellite to validate data. The National Security data was validated through visits to SD-JSC, SAC and TAC headquarters visits, and the SAI subcontract.

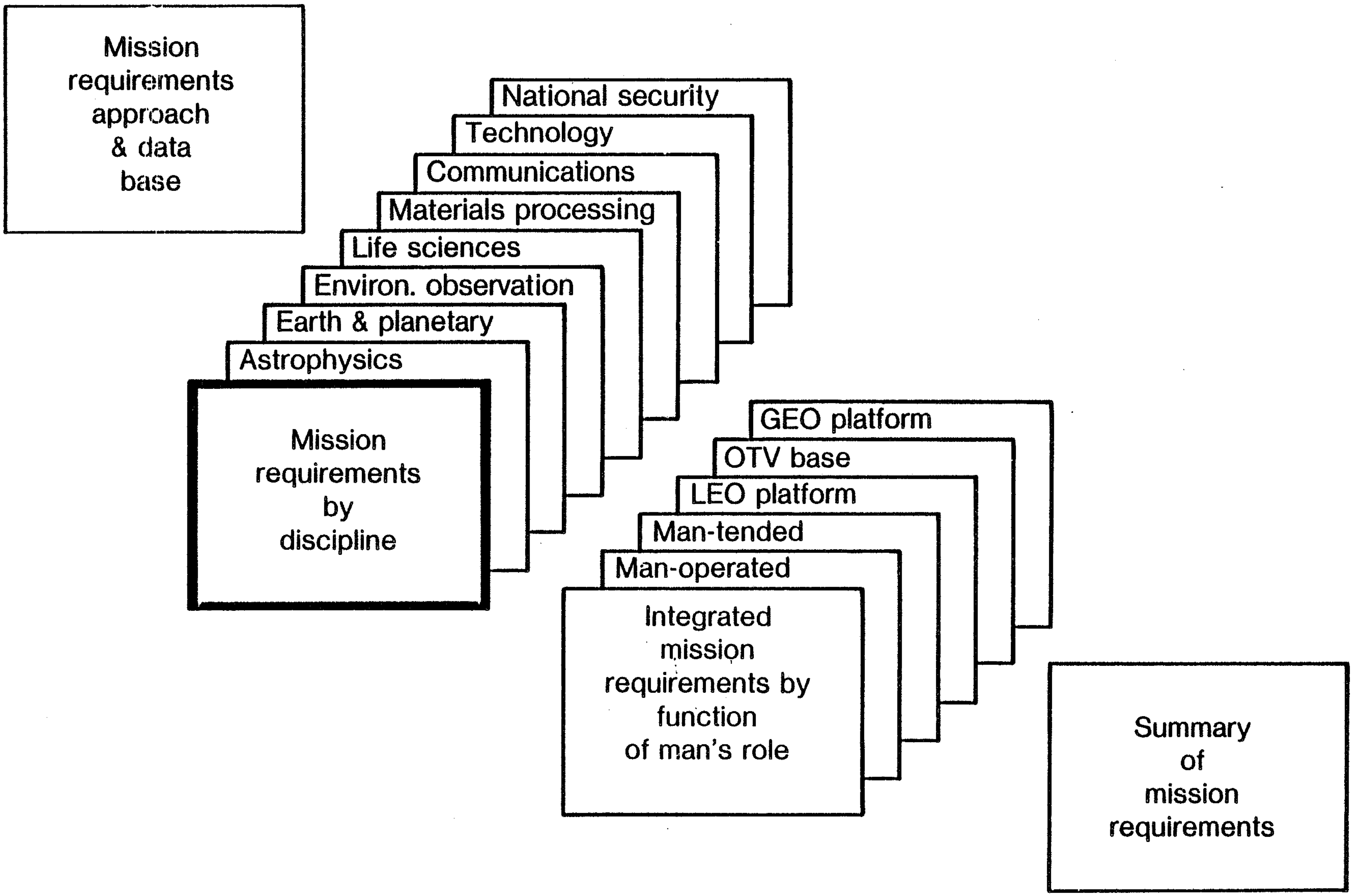
VALIDATION OF THE DATA BASE

	SCIENCE & APPLICATIONS	COMMERCIAL
Astrophysics	MSFC visit LANL visit	—
Earth & planetary exploration	JPL visit Univ input	Oil Companies contacts
Environmental obs	MSFC visit	SoCal Ed input
Life sciences	NASA HQ, JSC, ARC visits Adv Tech S/C Univ visits & inputs	—
Materials processing	MSFC visit JPL contact SAI S/C	Comml inputs & discussions SAI S/C
Communications	—	Spacecom S/C American Satellite
National security	SD-JSC visit SAC/TAC Hq visits SAI S/C	—

Note: In addition to NASA & DoD provided inputs & previous NASA & DoD study reports

15112793-18

The mission requirements, obtained from the various sources, were initially cataloged by the NASA discipline categories. Where necessary, missing data were synthesized based upon earlier studies and available information. The requirements were then time phased and sorted by the three basic functions of: Man-operated, Man-tended free-flyers, and OTV base. The results of this initial analysis are presented in this section along with a summary of the DoD study activities. The organization of the material generally follows the NASA Mission Description Document outline.


Mission requirements approach & data base
National security
Technology
Communications
Materials processing
Life sciences
Environ. observation
Earth & planetary
Astrophysics
Mission requirements by discipline
GEO platform
OTV base
LEO platform
Man-tended
Man-operated
Integrated mission requirements by function of man's role
Summary of mission requirements

15112793-54

The missions for each of the disciplines were first cataloged and an initial appraisal made of their suitability as a Space Station candidate. Secondly, they were segregated into the three primary functions of:

Man-operated
Man-tended free flyer
OTV base

At the same time they were identified as being within the first, mid or last one-third of the 1990-2000 decade. These two listings are not presented in the review but will be part of the final study documentation.

Lastly, the time-phased charts were prepared for each of the three functional areas. These data are provided herein for each discipline. Over 160 missions were reviewed.

ANALYSIS OF MISSION REQUIREMENTS

Disciplines

Astrophysics
Earth & planetary exploration
Environmental observations
Life sciences
Materials processing
Communications
Technology development
National security missions

Missions planned

Potential station roles

Time phasing

15112793-37

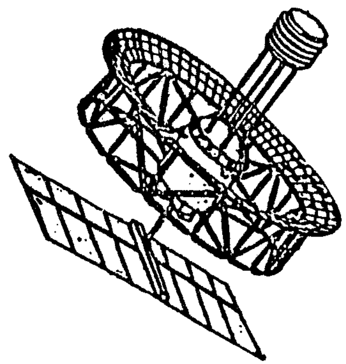
The general characteristics of the Astrophysics experiments are depicted, showing that deployment into space varies from a partial space shuttle load to as many as three full shuttle loads. Few of the missions are altitude or inclination sensitive, although the pointing accuracy and pointing stability will require development programs. Another feature is the fact that the missions have been conceived for multiple purposes and actually become facilities which makes the useful life extend over many years. Contamination control for the sensor systems is a stringent requirement.

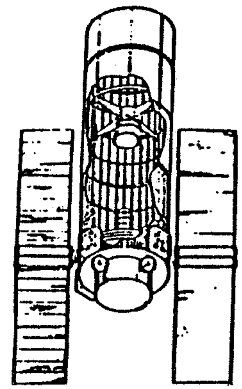
The manned Space Station assumes several roles in the support and use of the Astrophysics experiments. For the ones which are suitable, the experiment can be housed and operated at the Station. For others which are not resident, the station becomes an assembly way point, wherein the shuttle brings the vehicle to the station for final operational orbit via an OTV or teleoperator. To extend the life of the vehicle, service missions to refurbish and replenish with stores from the station can be performed via OTV or teleoperator. In some cases, later in the program, manned OTV support would significantly extend the life of a mission. At the end of the useful life, the vehicle is recovered and returned to the station for storage, refurbishment or returned to Earth.

Skills that will be needed are in the areas of space assembly and checkout; contamination control and cleaning; the maintenance of pointing accuracies; refueling; and replenishing cryogenics.

ASTROPHYSICS

- Astronomy
- High energy
- Solar physics





Characteristics

- Wide range of sizes & types
  —Very large, long-life observatories
  —Single & multiple STS flights
  —Smaller telescopes & sensor sets
  —Partial STS loads
- Many service-dependent for long-term useful life
- Majority of missions — 28½ deg — station altitudes

Potential station role

- Man-tending free-flyers
  —On-orbit assembly, checkout & calibration
  —Update & servicing of sensors & subsystems
  —Replenishment of consumables
- Manned operation & resource provisioning of station-attached telescopes
- Develop assembly & checkout techniques

Driving requirements

- Size
- Contamination limits
- Pointing accuracy

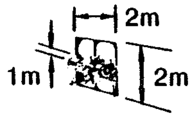
A representative set of vehicles is used to show the range of activities that could be expected of the manned Space Station in support of these missions. The X-Ray Timing Explorer, although initially conceived as a shuttle launched free-flyer, makes an ideal candidate for a resident spot on the station. As a result, the overall utility of the mission is significantly enhanced with regard to both costs and utility.

The second example was chosen to illustrate that many trade-off studies would be required before a decision could be made as to the location of the vehicle, as a station entity or as a free-flyer. Some of these trade-off studies would be concerned with the operation of the mission vs the operation of the station to determine appropriate operational time slots. Another is the ability to design the vehicle for greater utility and cost effectiveness for assembly at the station for installation in the station or as a free-flyer, and the problems concerned with space assembly and checkout. Another is to specify manual vs automated operation of the mission in the modes needed for greatest experimental value to the scientist. And studies of EVA activities during assembly and later to support the vehicle will be needed.

The third example is clearly a free-flyer and points out that even under those conditions the station plays a role in that the vehicle could be checked out at the station before being sent into operational orbit, and the station provides a base for the OTV/Teleoperator used to retrieve the vehicle at the end of its life.

ASTROPHYSICS MISSIONS — STATION ATTACHED vs FREE-FLYER OPERATIONS

GENERAL DYNAMICS
Convair Division

	Example Missions				
Operating Mode Selection Factor	X-ray Timing Explorer		Infrared Interferometer in Space		Gravity probe-B
Size mass	 1,000 kg		 22,500 kg		 1,530 kg
Assembly reqmts No. of shuttle flgts	Installation/C.O.		Final at station 1 or 2		1
Orbit — Orientation Altitude Pointing accuracy Environ reqmts	28.5 deg 400 km 36 arc sec		28.5 deg 400 km — 700 km ≈0.01 arc sec no contamination		Polar 600 km
Operations — M/H per shift					
Service — Frequency Duration	Maintenance as needed		Cryrogenic refills 1-2 years		None
Mission duration	2 years		5 years		1 year
Power data	1.2 kW 10 kBs				
Selected mode basis	Station Orbit, accuracy, time utility, size		TBD		Free-flyer Orbit
Remarks	Original concept as a free-flyer; possible life ext. on station		More design & operation data needed. Needs several trade studies to determine location. Assembly at orbit requires station opns		

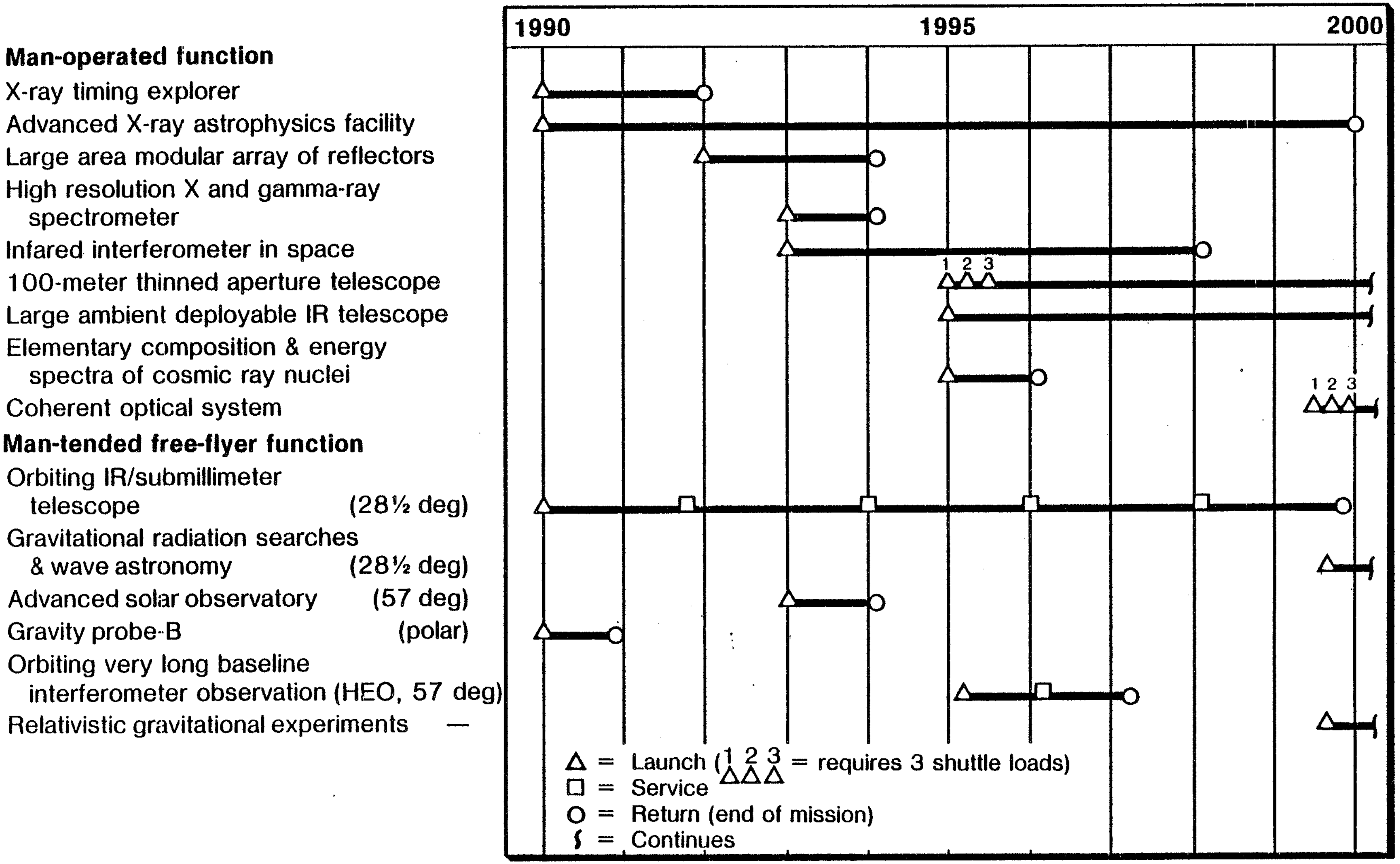
15112793-75

Many of the Astrophysics functions are facilities or observatories designed to accommodate a large number of experiments which can be included in their capability. Further, the design takes into account a myriad of guest investigators who will come to the appropriate NASA center to run their experiment. In rare cases, even, it is conceivable that the investigator could actually be sent to the Space Station to perform his experiment.

In the selection process to choose candidates that would require or whose utility would be enhanced by the Space Station, many possible vehicles were eliminated because the proposed operational time frame was before the station would be ready for use. If, as these experiments become fact, the time frame moves into the station operational era, they too would become good station residents.

MISSION REQUIREMENTS TIME PHASING

Astrophysics



15112793-61

The Earth and Planetary missions continue the exploration of the solar system. This included all of the solar planets for study of their general characteristics and some in more detail. For earth study, the missions will explore earth dynamics crustal motion and potential fields to more fully understand interrelationships that will permit prediction of the environment. Resources study includes renewable resources such as crops, both land and ocean, and nonrenewable, such as minerals.

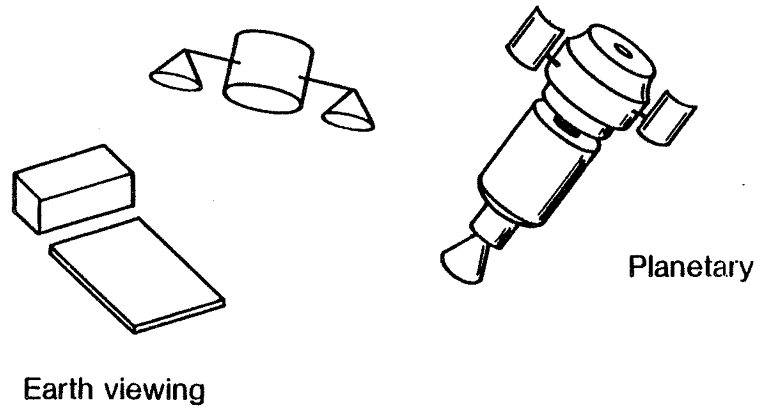
The characteristics include planetary landings for in situ study, as well as remote viewing and other remote sensing. A wide range of orbits is required for these missions as will be shown later. Some of the missions are for the development of instruments, sensors and techniques for use on later operations, which are included, to be supported by the Space Station.

This support by the Space Station will include the OTV delivery to HEO for both earth and planetary missions. Support of man-tended free-flyers is included. For the development of sensors and automated techniques for use on free-flyers, many of the missions will be conducted by man on the station.

There are several driving requirements such as orbit, instrument pointing, data rates, RF noise susceptibility, and electrical power. These requirements for planetary missions are relatively easy to accommodate by the Space Station in a low inclined orbit in conjunction with the OTV. This same station can accommodate most of the development missions. However, for the earth dynamics and earth resources operational missions, which require near total global coverage, highly inclined orbits, up to polar are required.

EARTH & PLANETARY EXPLORATION

- Planetary observations
- Solar system missions
- Earth dynamics
- Crustal motion
- Geopotential fields
- Earth resources



Characteristics

- Viewing systems & planetary landers
- Wide range of orbits
  —Planetary/escape
  —High altitude/HEO
  —LEO high inclination, incl sun-synch
- Broad spectrum of sensors, RF, optical, LIDAR
- Development & operational missions

Potential station role

- OTV basing for delivery to HEO — Earth & planetary
- Man-tending free-flyers in LEO
  —Singular or grouped on platforms
- Man-conducted development of station mounted sensors, analytical & automated techniques

Driving requirements

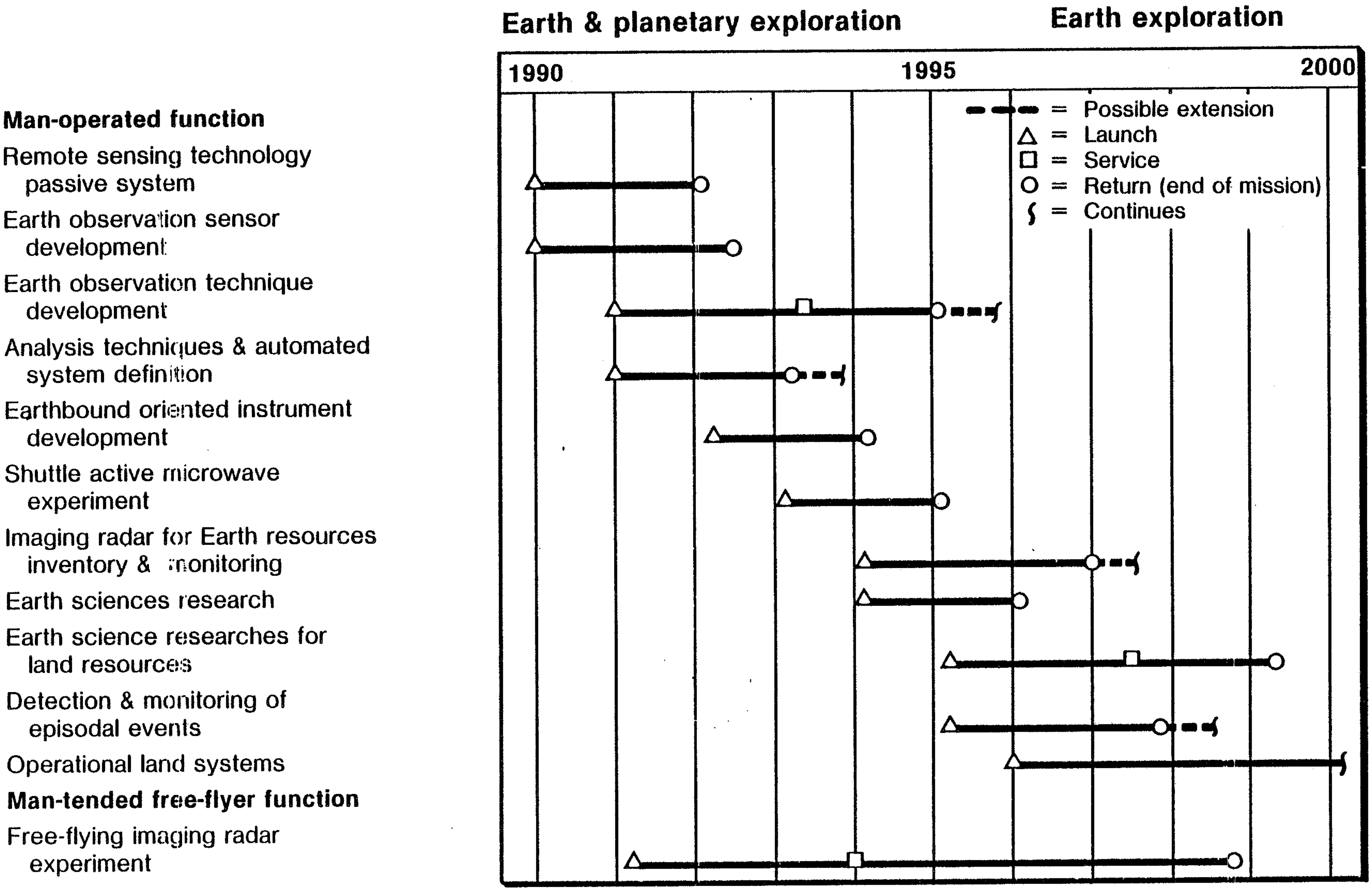
- Orbit range
- Orientation & pointing
- Data rates
- RF generation & susceptibility
- Power

15112793-67

The time phasing functions of the Earth and Planetary Exploration missions, discussed in the previous chart, could be performed as shown by initially conducting the development activity aboard the Space Station using man in this most effective way to operate instruments and interpret data as performed in the earth bound laboratories. The schedule shows a progression to more advanced missions.

The man-tended free-flyer function shows a schedule for the FIREX mission which could be initially placed in a near polar orbit, recovered for refurbishment, and then deployed for additional operating time.

MISSION REQUIREMENTS TIME PHASING



15112793-63

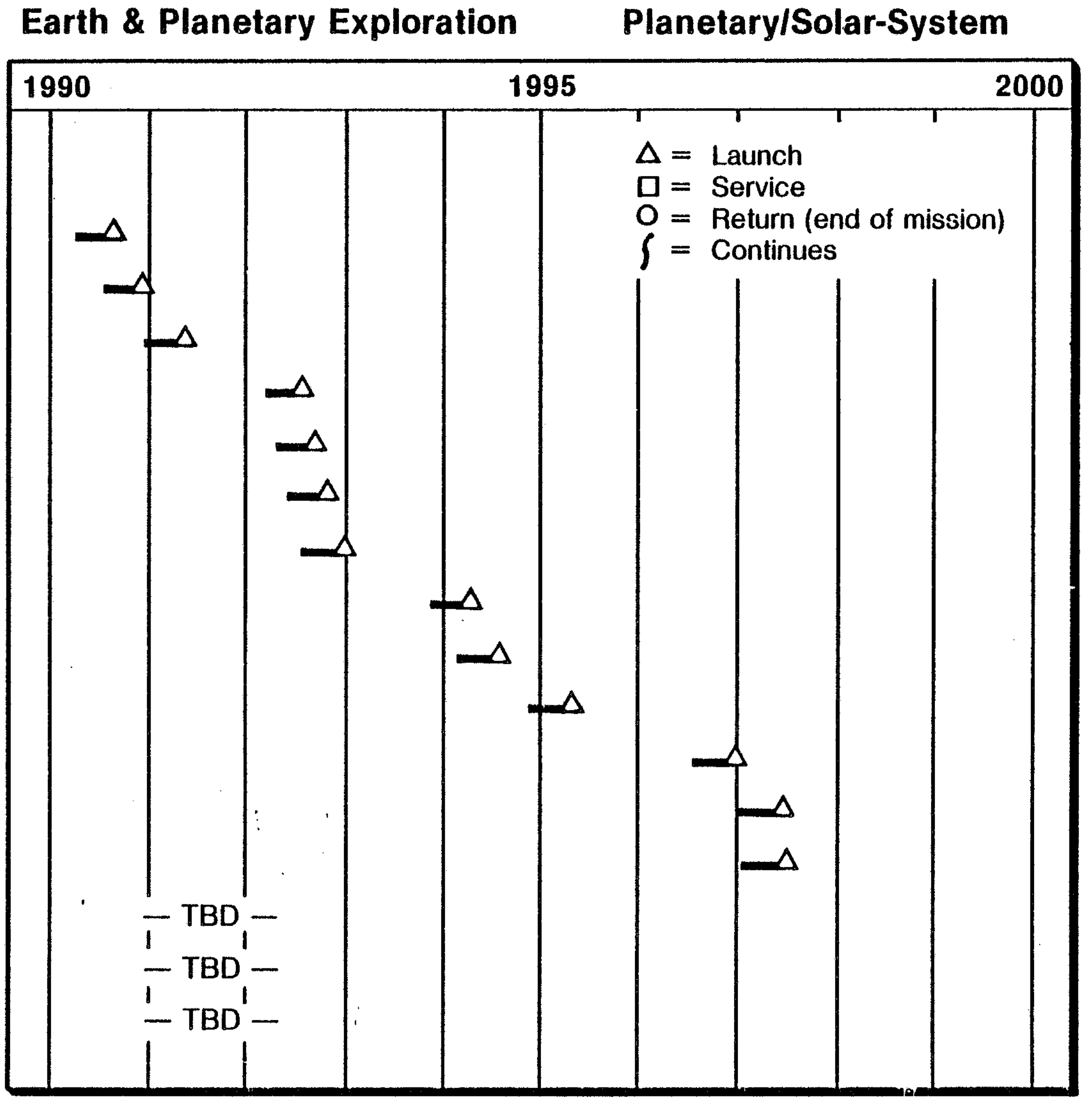
A candidate launch scenario is shown for missions to the inner planets, outer planets, and small bodies of the solar system. The missions included are those given most attention by agencies and authorities in this field, both in their literature and in GDC contacts. The time phasing shows only the launch dates from LEO to escape trajectory since this is the area of principal involvement with the Space Station. Some of the missions extend several years beyond the launch date, and the sample return missions conclude with the sample module returning to LEO for retrieval by the station.

At this writing the Solar System Exploration Committee (SSEC) is preparing to release its recommendations to NASA for planetary missions to be undertaken by the year 2000. These recommendations will impact the mission mix shown here, and will be factored into the final report in this study.

MISSION REQUIREMENTS TIME PHASING

OTV base function (28½ deg)

Mars orbiter
Comet HMP rendezvous
Venus radar mapper
Comet T2 rendezvous
Asteroid multiple rendezvous
Main-belt asteroid rendezvous
Uranus-Neptune probes
Comet HMP sample return
Mercury orbiter
Titan probe
Mars surface sample return
Saturn orbiter
Near-Earth asteroid rendezvous
Uranus orbiter
Jupiter-Neptune flyby
Jupiter-Pluto flyby



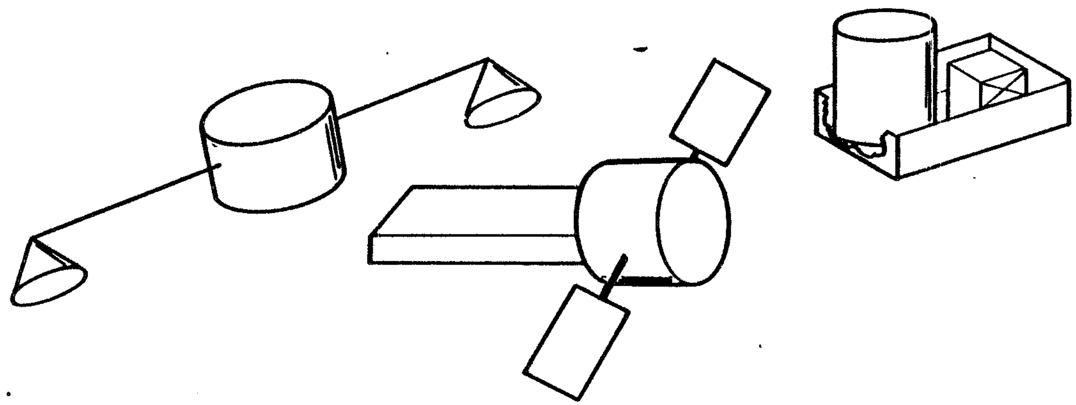
Environmental Observations Missions include investigations and data gathering in the disciplines of Weather and Climate, Ocean observations, Solar/Terrestrial interactions, and Atmospheric Research. These missions employ both passive remote sensing of natural phenomena, and also active stimulation using lasers, plasma wave injection facilities, electron beams, and powerful radars.

Early year missions for development of payload equipment and measurement techniques can make use of low inclination orbits and will benefit from man's presence for instrument adjustments and servicing. Later operational missions desire high inclination orbits to provide global coverage and access to the auroral zones. Man's presence for these operational missions would also be beneficial, although many of the observation functions can be automated.

The LEO missions range from 28½° to 98° inclinations, and several of the meteorological missions require GEO vantage points.

ENVIRONMENTAL OBSERVATIONS

- Weather/climate
- Ocean
- Solar/terrestrial
- Atmospheric research



Earth & atmosphere viewing

Characteristics

- Viewing systems — broad spectrum RF & optical
- Orbit range
  GEO, HEO
  LEO — high inclination & sun-synch
- Large size sensors, including LIDAR
- Development & operational missions

Potential station role

- OTV basing for checkout & delivery to HEO & GEO
- Man-tending free-flyers —Singular or platform groupings
- Manned development of sensor systems

Driving requirements

- Orbit range
- Orientation & pointing
- Data rates
- Power (to 25 kW)

Missions that require manned operation in the early period are for development of individual instruments and for the integration of multisensor groups which will later be operated simultaneously for broad spectrum (i.e., R.F., Optical, IR) measurements of earth, atmosphere and solar emissions, and measurements of atmosphere constituents.

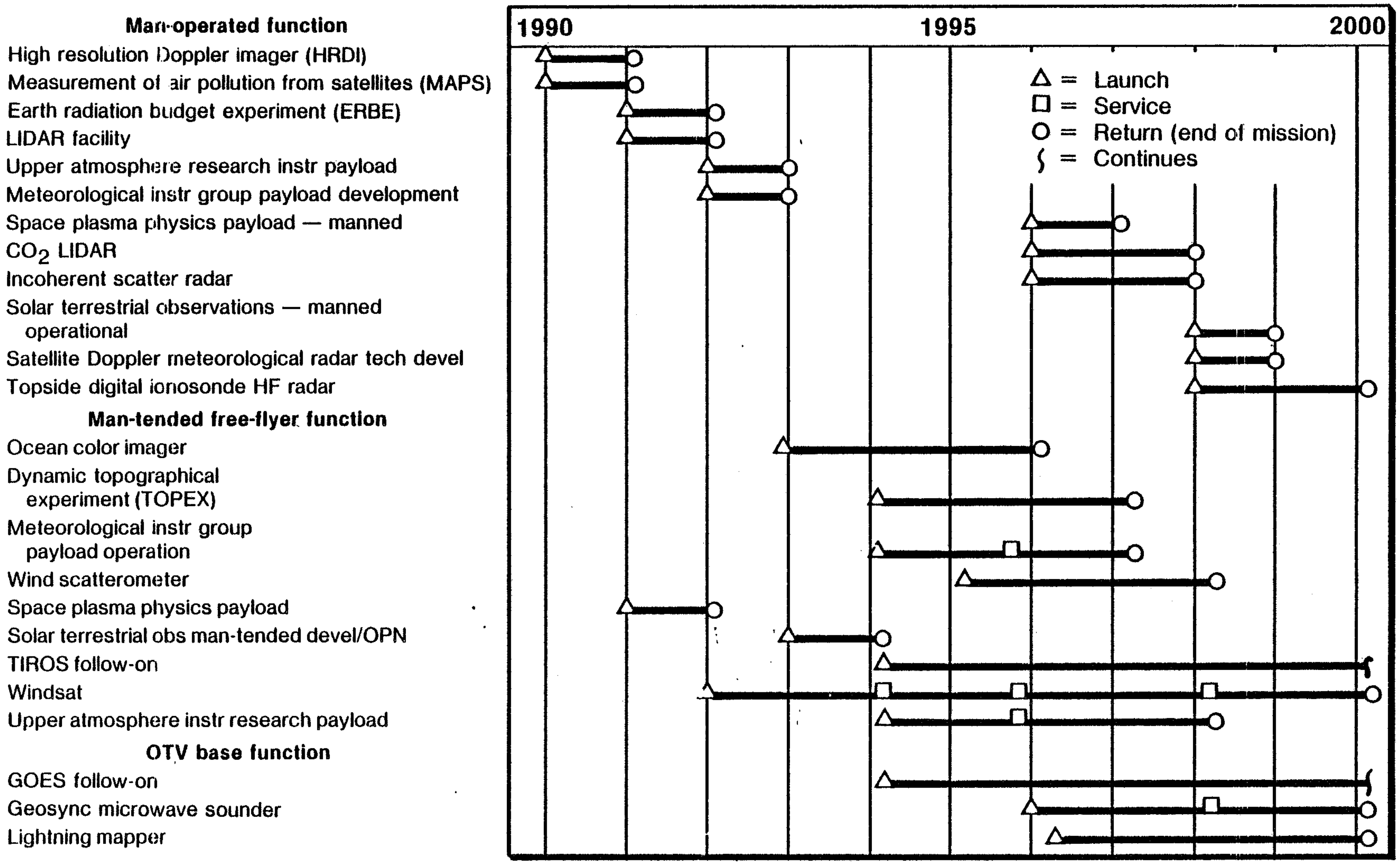
Free flying LEO satellites and platforms will carry environmental observations sensors throughout the decade and beyond. These will present many opportunities for Space Station support for servicing, updating and repair. Where significant changes in orbit altitude or inclination are required to emplace or retrieve satellites, a Space Station-based TMS or OTV could provide a significant economic benefit over dedicated Shuttle servicing missions.

In the later years many of the missions involve the assembly, alignment, checkout and use of physically large structures and antennas. High input power levels are also required.

The GEO meteorological mission requirements can potentially be satisfied by GEO platform accommodations in lieu of individual satellites.

MISSION REQUIREMENTS TIME PHASING

Environmental observations



15112793-62

Life Sciences disciplines will derive substantial benefit from a Space Station. Existing research opportunities in Spacelab are severely limited by the 7-10 day mission duration and tight budget for crew time and power. The Space Station will provide the capability for long duration missions, nominally 90 days for each crew, and continuous residency in space for animals and plants. The long mission duration allows investigation to proceed on the long term effects of microgravity, e.g., changes in bone, muscle, and blood, the long term effects of space radiation, and the effects of mission duration on human performance. These studies will be enhanced by the station's much larger budget of crew time and other resources to support a more complete investigative program with less scientific compromise and more room for contingency operations in the conduct of each experiment.

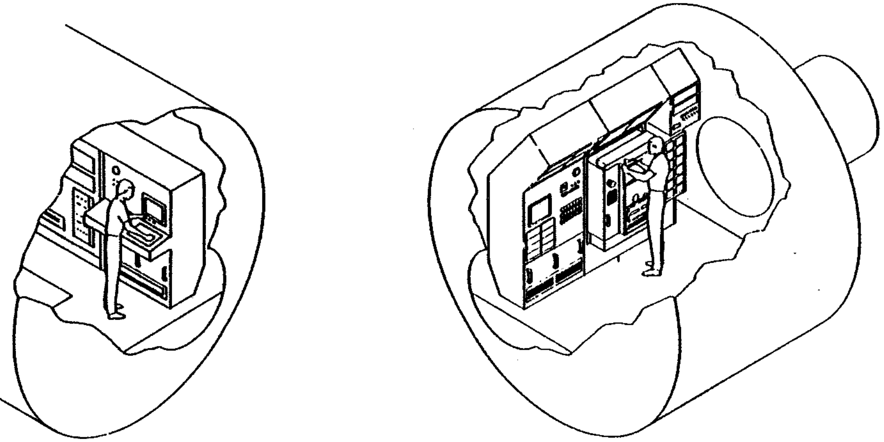
In a manned space mission, the first concern of life sciences is Operational Medicine. A manned Space Station will initially need to have a basic health maintenance capability and medical care equipment/supplies for routine and emergency care. Eventually, as crew size increases, additional onboard diagnostic and therapeutic capability and a dedicated health maintenance/medical clinic facility will be warranted.

Potential Space Station roles in Biological Science will include long duration research of human physiology and psychology, animal and plant physiology, and cellular and developmental biology. A broad spectrum of research into microgravity effects on human physiology and on basic biological systems is needed to address operational medical concerns and to elucidate basic mechanisms of adaptation to space.

Finally, the opportunity will exist to perform 0-g verification tests of advanced Life Support Systems for H_2O reclamation, O_2 generation, and CO_2 removal/reduction, and to test components of controlled ecological life support systems, such as organic waste processors and plant growth chambers for eventual onboard food production.

LIFE SCIENCES

- Biological science
- Operational medicine
- Life support



Medical care

Research support lab

Holding facilities —plants & animals

Characteristics

- Research labs & live specimen holding facilities in LEO
- Crew health care equipment
- Development payloads for self-sufficient life support & EVA

Potential station role

- Long duration research —humans, animals, plants
- Food growth and air & water renewal
- Lifetime holding of plants & animals
- Measurement/improvement of crew performance — station & EVA

Driving requirements

- Man conducted research —required time & skills
- Specimen care
- Disturbance g limits —for some plants
- Centrifuge accommodations
- Crew medical care for long duration

15112793-65

Life Sciences mission requirements from the three areas, Operational Medicine, Biological Sciences, and Life Support Systems, are grouped in five facility/equipment categories below.

Medical facilities for the crew will initially consist of the Shuttle Orbiter Medical System permitting on-board care of simple illnesses and injuries, and means to stabilize serious medical conditions until return to Earth, and health maintenance capability providing for exercise, e.g. treadmill, and simple biomedical monitoring (heart rate, ECG). Early years upgrades will include items such as clinical biochemistry, microbiology and medical imaging systems and an IV fluids capability. An extensive EVA workload is anticipated, increasing the chances for anomalies causing decompression sickness. This is deemed to justify the early presence of a hyperbaric chamber. Regarding radiation shielding, a middle years decision can be made based on accumulated experience. In later years, a dedicated medical clinic is included to treat serious medical conditions in orbit.

A dedicated Human Research Laboratory is planned, starting in 1990, with periodic upgrades during the decade as new and follow-on experiments are added and old equipment is replaced. Human research will span the areas of bone mineral and muscle metabolism, hematology, immunology, radiation effects, cardiovascular and pulmonary physiology, endocrinology, neurovestibular physiology and psychology. Instrumentation for EVA workload and human performance assessment will be upgraded as new tools and procedures are developed.

A dedicated Animal and Plant Holding Facility is planned starting in 1990 to provide environmentally isolated home for animals (rats, mice, small primates) and plants, including a 1-g centrifuge for plants and small animals. Initially, the facility contains a work station for animal/plant manipulation, and instrumentation for monitoring/analysis. During the middle years, a separate Animal and Plant Research Lab will be added (with centrifuge for larger animals) and can also contain (option) the original plant holding units and related equipment; the original plant volume can be used for larger primates. In later years, the animal facilities would be upgraded to accommodate still larger primates.

Finally, station resources are planned for 0-g verification tests of new Life Support Systems components. Physio-chemical processes for H_2O reclamation, O_2 generation, and CO_2 removal/reduction and biological processes for food and wates will be tested starting in the early years, and new modules incorporated into the Station's operational systems in later years. Controlled Ecological Life Support Systems will process spent consumables and produce food, as well as some air/water, appreciably reducing the need to import life sustaining supplies from Earth.

MISSION REQUIREMENTS TIME PHASING

△ = Launch
□ = Service (upgrade)
+ = Becomes operational
○ = Return (end of mission)
∫ = Continues

Man-operated functions

Medical facilities for crew

- Shuttle medical kit, exercise station, biomedical monitoring
- Hyperbaric chamber
- Radiation shielding
- Dedicated medical clinic & health maintenance facility

Human research laboratory

- Human physiological research
- Human performance measurement & enhancement (EVA & IVA)

Animal & plant holding facility

- Smaller animals, plants, centrifuge, work station
- Larger primates

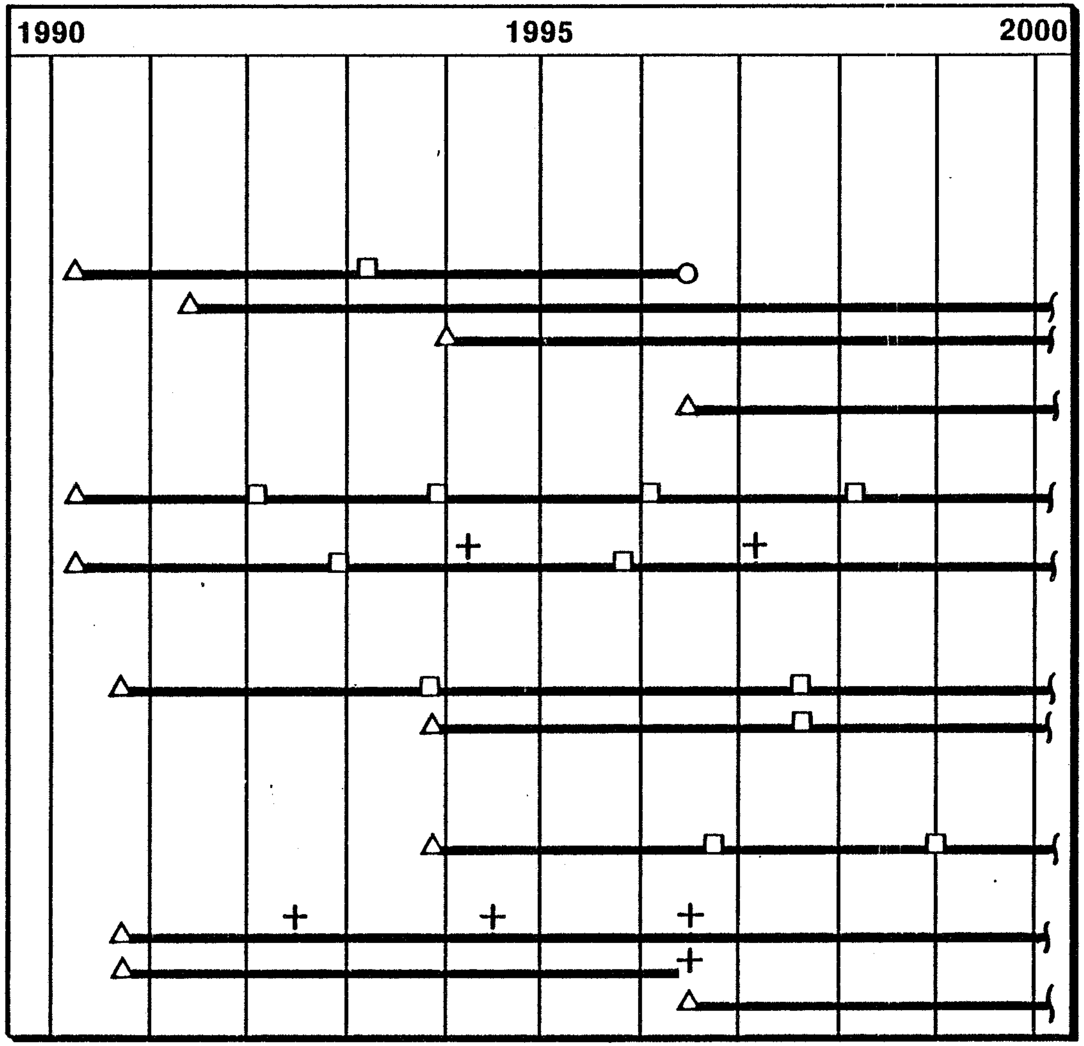
Animal & plant research lab

- Plant holding, work stations, centrifuge

Life support systems (0-g test)

- $H_2O/O_2/CO_2$ regenerative systems
- CELSS experimental systems
- Dedicated CELSS module & pallet

Life sciences



15112793-57

Materials Processing mission requirements are expressed in terms of an evolutionary complement of facilities which will be accommodated/supported by the Space Station.

General purpose research facilities will be required from the outset which will provide a continuation of Spacelab MPS research capabilities for academic and industrial users. The initial facility will provide small scale experiment capabilities in all materials science areas and also fluid physics experiment capabilities. Analysis of the properties of the materials produced will be primarily ground-based. The research facility capabilities will expand with time to enable the production of larger and/or more complex products and will include equipment for some types of on-orbit analysis of material properties.

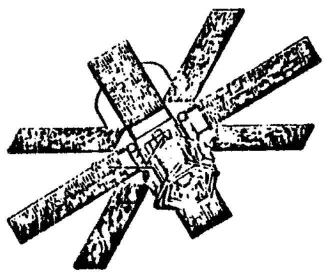
When high potential for economically viable processes has been developed, specialized facilities for pilot production plants will be required to further develop equipment and to optimize the processes. Those processes/products that are proven in the preceding phase will advance to full scale commercial production in dedicated facilities.

Research experiments and pilot production will be relatively labor intensive because of the high level of manned involvement in controlling test conditions and observing results. However, the production facilities will be automated for long term production runs.

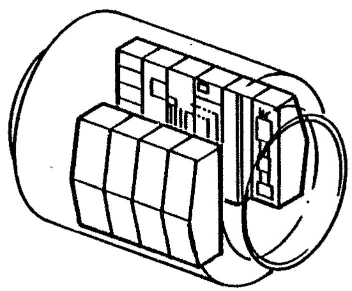
The free flying biologicals production spacecraft is currently planned to begin operation in 1986-1987 with servicing revisits by the Space Shuttle every six months. This servicing function could be assumed by the Space Station if economic benefits can be derived.

Throughout all phases of commercial experimentation and production, the facility arrangements, operational procedures, manning, logistics, data handling and communications must insure the protection of proprietary information.

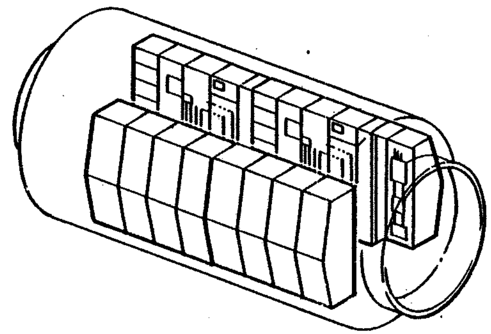
MATERIALS PROCESSING



Commercial free-flyer facility



Station R&D facilities



Station production facilities

Characteristics

- Station mounted equipment for commercial use & man-conducted R&D
- Commercial facilities in free-flyer in LEO

Potential station role

- Long duration manned research activities
- Station resources
- Service & update free-flyers

Driving requirements

- Man-conducted research
  —Required crew time
- Power levels
- Disturbance g limits
- Logistics
  —Materials weight, volume & thermal control

15112793-70

The nine facilities shown opposite represent the spectrum of MPS facilities envisioned through the year 2000. General purpose research facilities, shared by all types of users, will be required throughout the entire period, with both experimental and analytical capabilities increasing with time. Because of the large number and variety of MPS experiments and development activities that are envisioned, it is not feasible to show them in a detailed timeline at present.

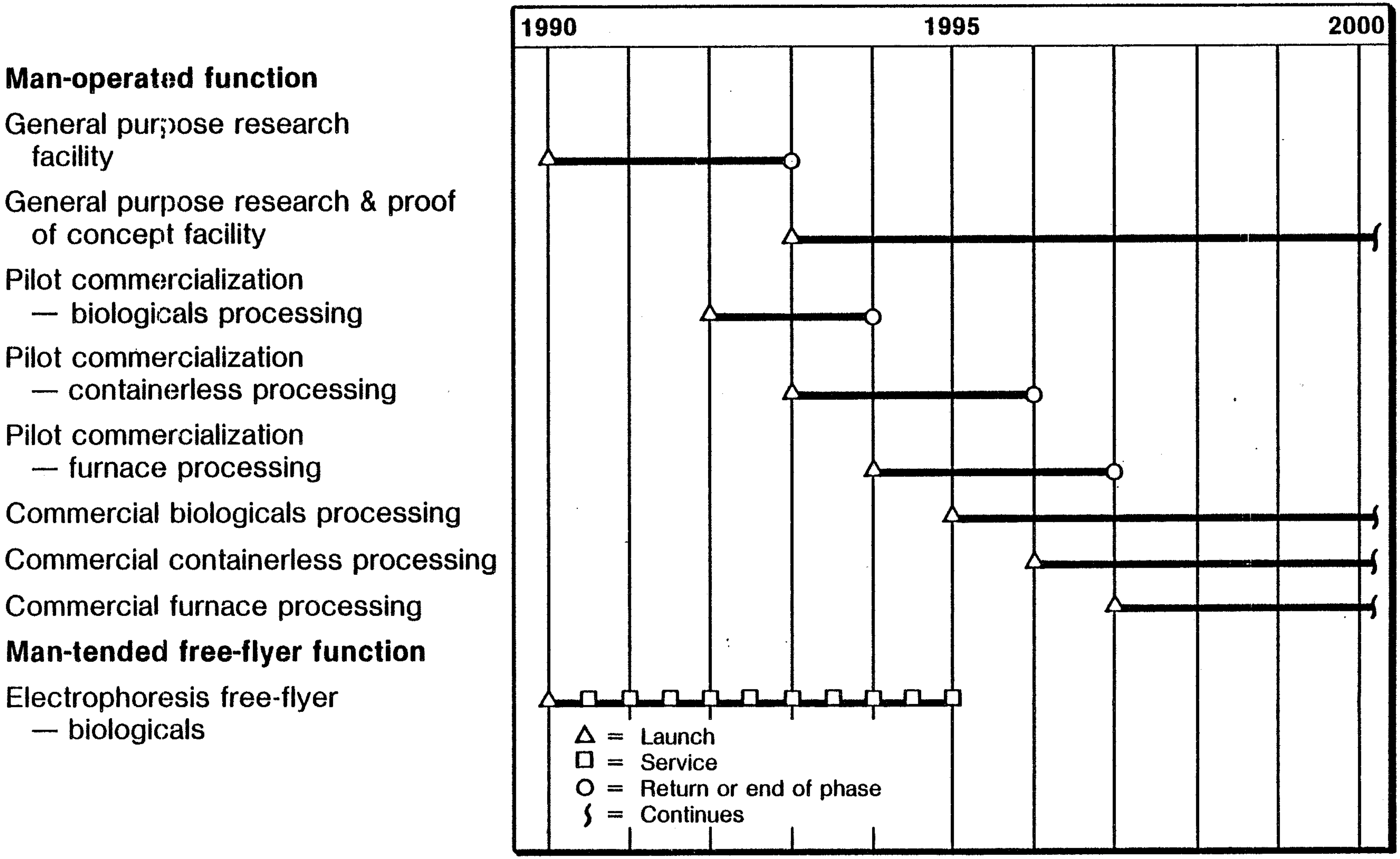
Time phasing shown for the pilot commercialization and full scale commercial processing facilities follows a logical progression from Spacelab and early Space Station MPS research. However, no schedule commitments from potential commercial users have been obtained at this early date, primarily because commercial processing in space is perceived to be beyond the nominal 10-year investment horizon.

The microgravity requirements for these facilities range from 10^{-3} to 10^{-5} g for various time durations. All of the facilities require vacuum ports.

It is assumed that by 1990, MPS free-flyers may already be in operation, such as for commercial-scale electrophoretic separation of pharmaceuticals. For a variety of reasons, free-flyers may continue to operate indefinitely throughout the Space Station era, with regular servicing (e.g., 6-month intervals) from the Space Station.

MISSION REQUIREMENTS TIME PHASING

Materials Processing



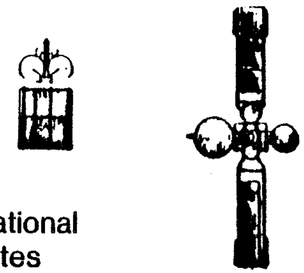
15112793-58

Communications includes two separate and distinct mission roles; (1) the Space Station/OTV support of communication satellites for boost to GEO, and (2) the technology development which will be performed at the Space Station for advanced communications technology.

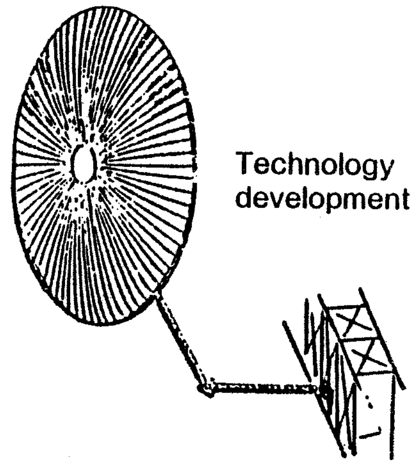
Communications traffic to GEO represents an existing and growing potential for Space Station operation as an OTV base. Shuttle delivered satellites can be grouped on an OTV without separate boost stages for GEO deployment. Future large satellites can be assembled, checked out and repaired at the Space Station. Eventually, multiple modules and antennas can be assembled at LEO and boosted to GEO at low (.1 - .2) g levels.

The Space Station can be employed as a platform to advance the development of communication satellite technology. Its large size, high prime power supply, availability of man to observe, photograph and assist, and recovery of the hardware makes it ideal for the communication satellite developers to employ as an in situ laboratory.

COMMUNICATIONS



Operational satellites



Technology development

Characteristics

- Operational satellites at GEO
- Advanced communications technology development in LEO

Potential station role

- OTV basing for delivery to GEO
- LEO assembly & checkout/repair
- Servicing — Retrieval to LEO
  — In-situ by OTV
- Manned development of station-attached advanced systems

Driving requirements

- Operating orbit — OTV base for boost to GEO
- Size

15112793-69

The time phasing for communication technology development places most of the experimentation in the early years of Space Station use. The reason for this is that commercial applications for this advanced technology already exists, and advanced satellites will be incorporating these advancements as soon as possible. Some of these experiments are "one time" endeavors, although continuing experimentation on similar items is entirely possible. Other experiments, such as RFI measurements and spaceborne interferometer use will be carried out over long time periods, but in a "monitoring" mode.

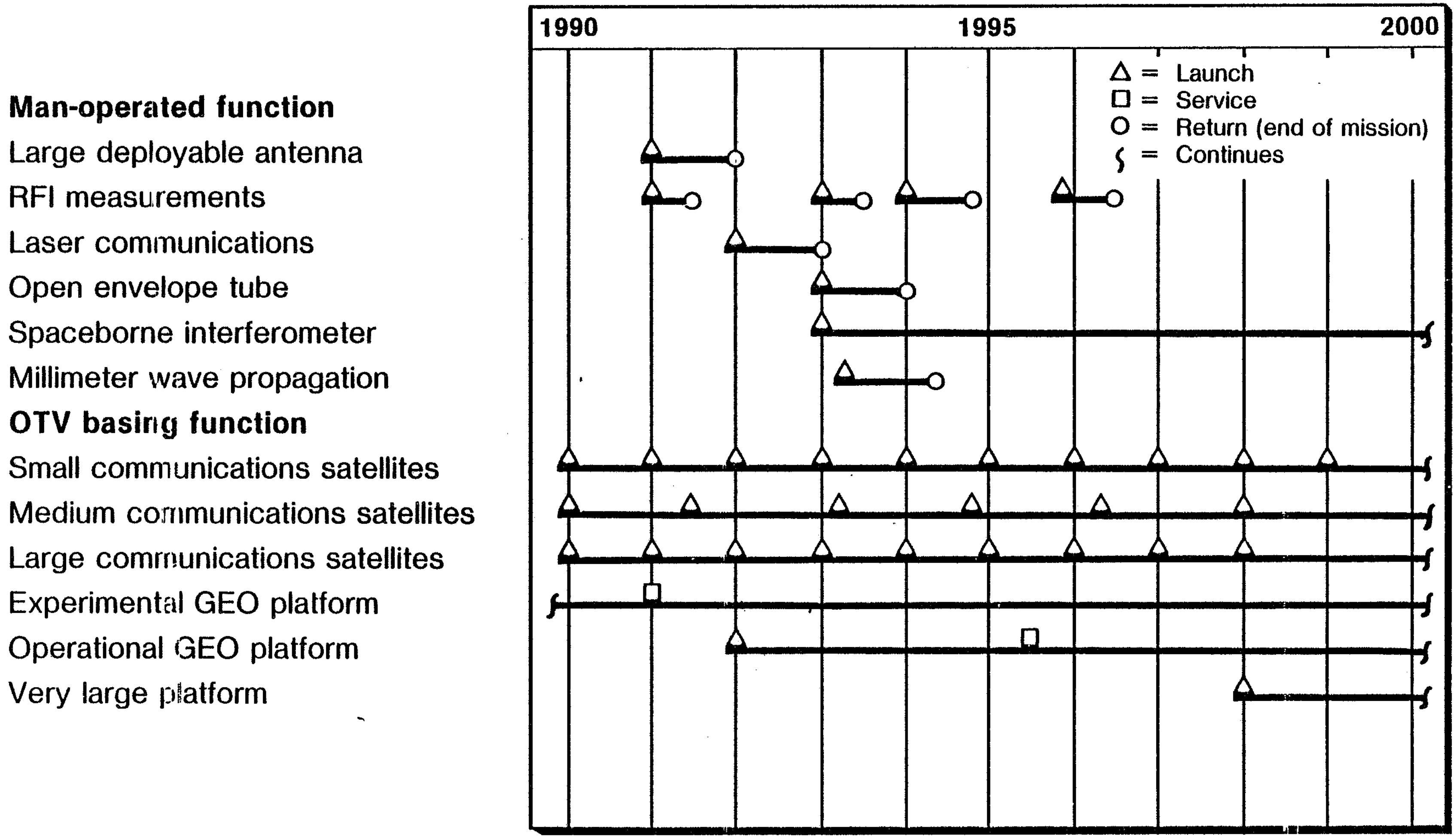
Construction of a large deployable antenna is key to many new areas of communication such as land mobile satellite service, direct broadcasting to homes, tracking and data acquisition, search and rescue. LASER communications, open envelope tube, and millimeter wave propagation are candidates for immediate commercial exploitation.

Small, medium and large satellites will be launched continuously over the period of 1990 through 2000 and beyond. The Space Station, and OTV when available, will be used in the boost of these satellites to GEO. The MSFC mission model, Rev. 6, schedules a launch of an experimental GEO platform in 1989 (with service in 1991) and several operational GEO platforms beginning in 1992. A very large platform (as yet undefined) is scheduled for 1998.

MISSION REQUIREMENTS TIME PHASING

Communications

Communications experiments
Communications payloads

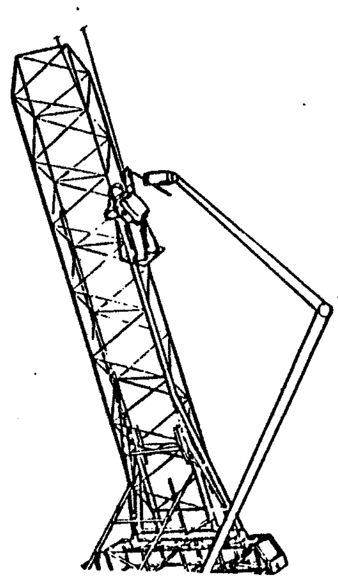


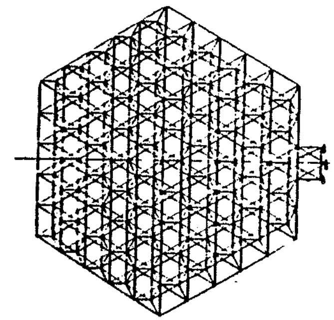
15112793-59

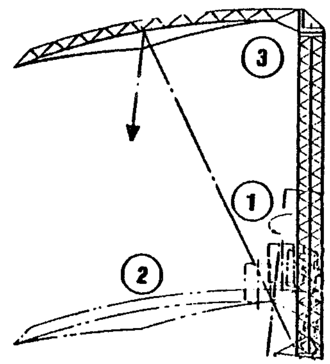
The technology experiments cover a broad range of disciplines and take place throughout the 1990's. Some missions call for very long exposure to the space environment, covering most of the decade. These are generally the investigations relating to long term effects on properties and performance, as exemplified by the experiments in materials and coatings, special sensors, and space component lifetimes. Other experiments such as those in advanced energy conversion and controls technology have span times in the order of one year. The station provides the necessary characteristics of low gravity, availability of power, man/experiment interaction, data processing, and long-term presence in the space environment to facilitate the technology development missions.

TECHNOLOGY DEVELOPMENT

- Materials & structures
- Energy conversion
- Computer science & electronics
- Propulsion
- Control & human factors
- Space station systems/ops
- Fluid & thermal physics/pace







Characteristics

- Wide size & mass range of attached structures, panels & packaged system experiments
- Stable platform required for testing of integral & attached spacecraft systems & components
- Experiment durations from one week to 20 years
- Frequent changeout of test systems & components

Potential Station Roles

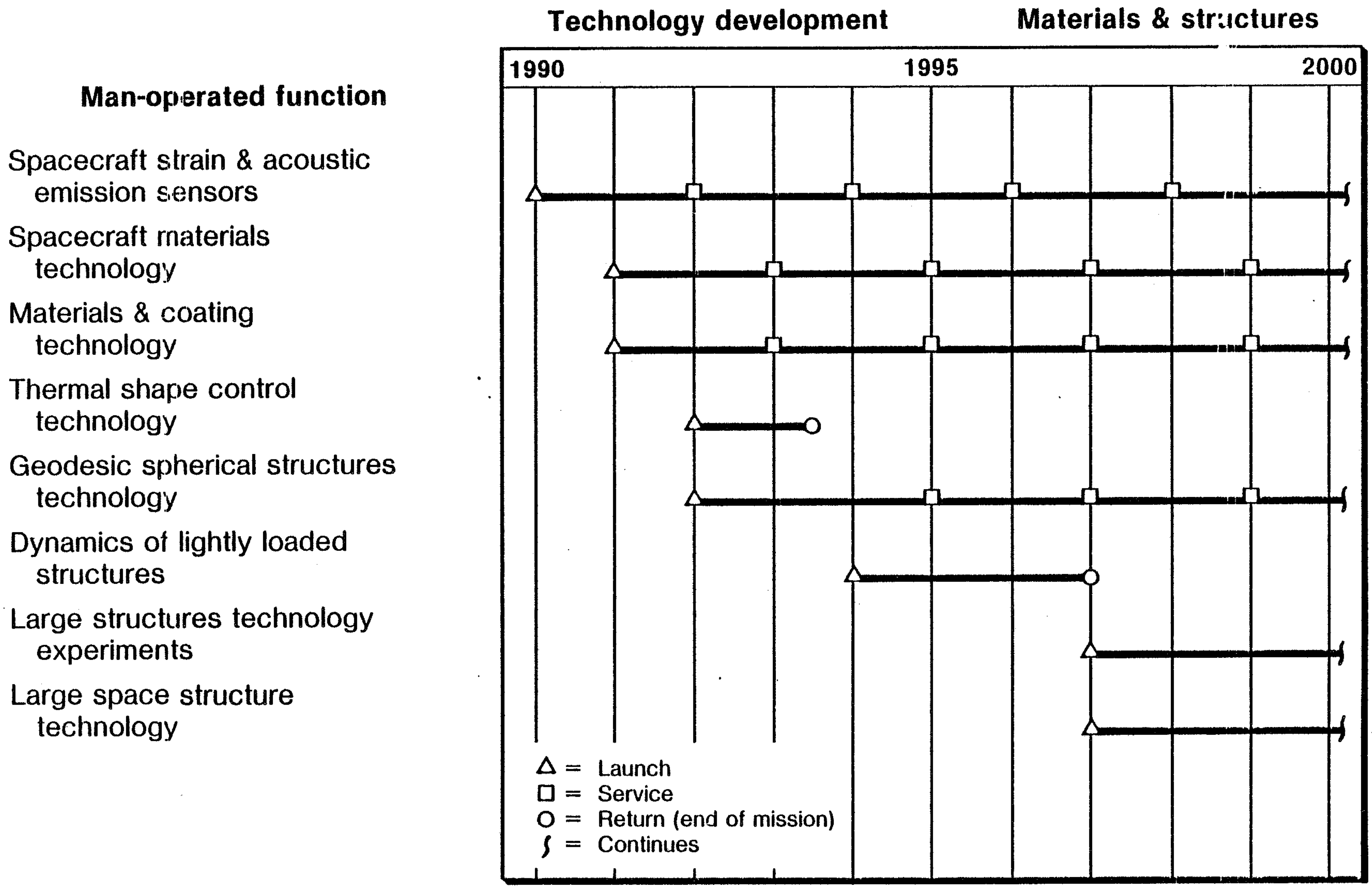
- Crew activity for
  - Structures assembly
  - Hardware changeout
  - Systems operation
  - TMS operations
  - Test observation/ evaluation
- Constant use of data acquisition & analysis facility

Driving requirements

- Accommodation of large structures
- Platform stability
- Data acquisition & analysis
- TMS control center
- EVA

This group of experiments establishes a data base for the deployment of structures in space. Long term tests are performed on advanced materials and coating, as well as specialized sensors for nondestructive evaluation, extending through the decade. The investigation into dynamics of lightly loaded structures tests the premise that for structures erected in zero g, flimsy components may be perfectly adequate. Thermal shape technology is an interesting experiment in which heaters are applied to a flexible panel for control of its shape by varying the local temperature distribution. Large structures technology experiments will establish both techniques and a data base for erecting large structures in space.

MISSION REQUIREMENTS TIME PHASING



15112793-109

In this group of missions the Computer Science experiments focuses on validating hardware, algorithms and systems for attitude control of Space Station and flexible payloads. The Manipulator Controls Technology Experiment will determine the characteristics and limitations of control technology applied to space teleoperator systems. The Space Station Systems missions provide technical verification and life demonstration of various systems such as an advanced liquid droplet radiator, spaceborne power units, propulsion systems and navigational devices.

MISSION REQUIREMENTS TIME PHASING

Technology Development

Computer science
Control & human factors
Space station systems

Man-operated function

Liquid droplet radiator

Advanced control drive technology demonstration

Space component lifetime technology

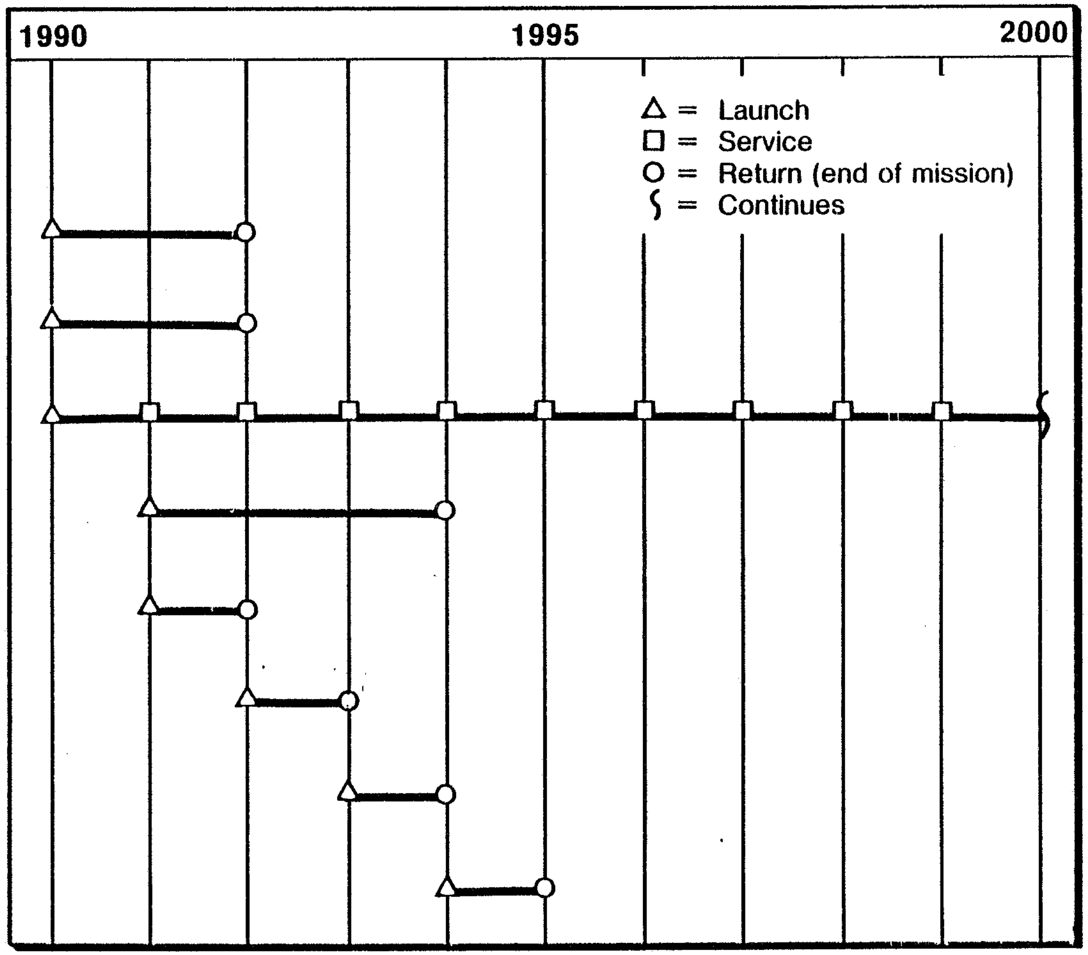
Manipulator controls technology

Attitude control-system identification experiment

Attitude control-adaptive control experiment

Attitude control-distributed control experiment

Advanced adaptive control technology demonstration



The energy conversion experiments focus both on low cost and advanced technology approaches. The low cost solar panels are deployed for the entire decade to provide data on long term endurance characteristics in the space environment. In the large space power experiment, a large solar array is assembled in modular form, capable of generating power at various high voltages which is converted to AC for efficient transmission. It is tested first in the natural space environment and then in the proximity of an ion engine. A series of tests on a large solar concentrator establishes the optical characteristics of the mirror then utilizes the concentrated solar energy for experiments with solar pumped lasers and solar sustained plasmas.

MISSION REQUIREMENTS TIME PHASING

Technology development **Energy conversion**

Man-operated function

Low cost modular solar panel technology

Large space power system technology demonstration

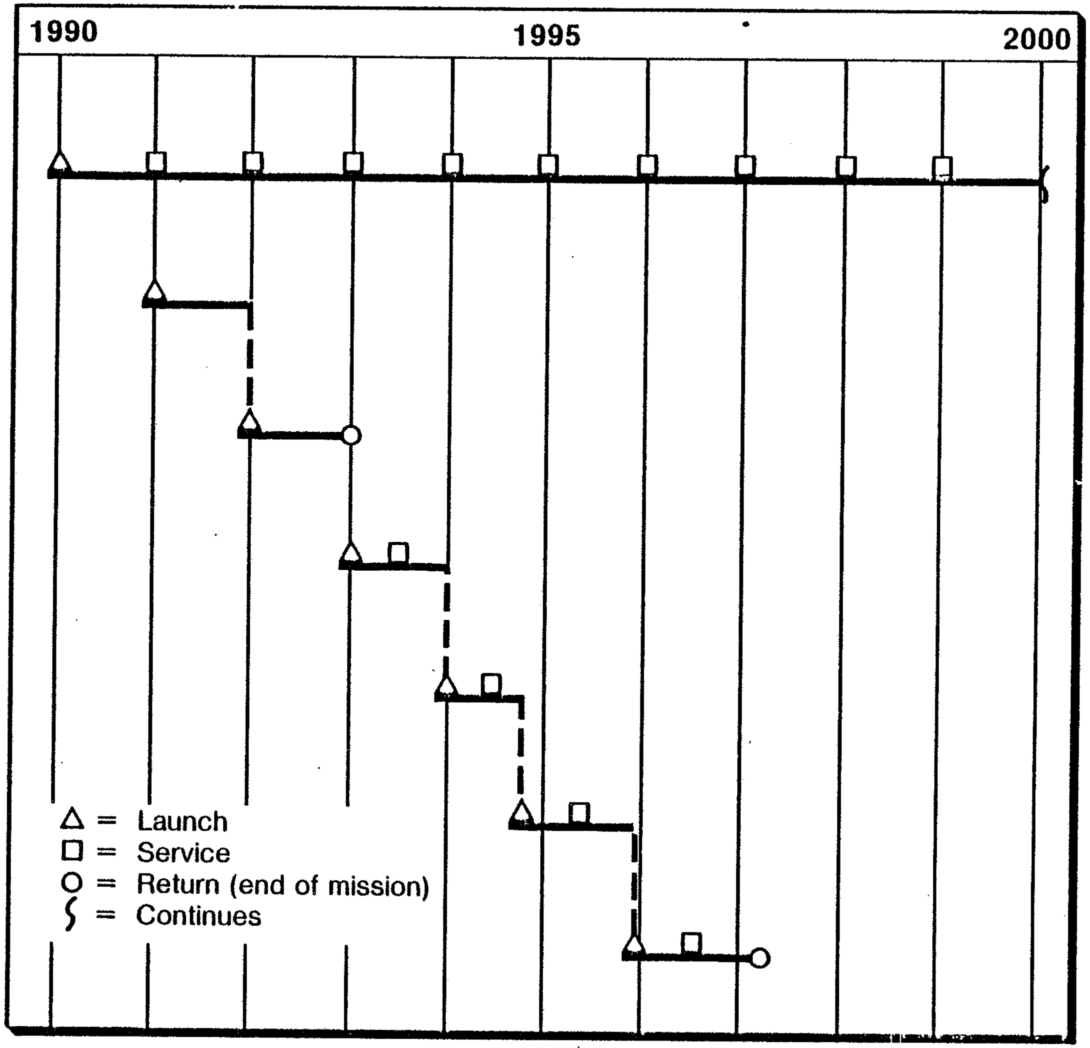
Ion thruster effects on LEO power systems

AER-I: deployment & testing of large solar concentrator

AER-II: test solar-pumped lasers

AER-III: laser-to-electric energy conversion

AER-V: solar-sustained plasmas



15112793-108

We see business opportunities for use of a Space Station to provide earth observations data falling into four basic categories:

- Geological surveys and petroleum exploration
- Earth Resource Management for Agriculture and Forestry
- Ocean Resource Management
- Atmospheric Monitoring, e.g. pollution

These are in turn supported by the missions shown.

In making contacts within the business community, we found firms who expressed specific interest in two areas: petroleum exploration and pollution monitoring. Detailed mission data will be established in follow-up discussions with the interested firms. In addition, we will continue discussions with others to develop their potential interest. Although no firms replied with an interest in the renewable earth and ocean producing areas, we expect to be able to develop some data in these areas also.

COMMERCIAL EARTH & OCEAN OBSERVATIONS

Business opportunities

- Geology surveys/oil exploration *
- Earth resource management
  agriculture, forestry
- Ocean resource management
- Atmosphere pollution monitoring *

Missions to support opportunities

- Instrument development
- Surveys & data collection
- Monitoring & reporting conditions

***User interests positively identified**
Mission definitions incomplete

15112793-13

The benefits of placing communication satellites in space is a business opportunity which is already being exploited and can be further developed through the use of a manned Space Station with OTV basing. Once this capability is developed, large satellites can be assembled and checked out in LEO before mating to an OTV for a "low g" boost to GEO. The space-based OTV can be used to retrieve "failed" satellites from GEO for return to the Space Station for servicing and repair. An additional commercial application for the Space Station is the protected stowage of a space satellite. When needed, it could be placed in orbit in a minimum amount of time. These opportunities have been discussed with satellite developers, owners, and customers, with positive interest shown by those contacted.

The Space Station will also provide the base for technological development of new communication opportunities such as land/mobile communications employing advanced equipment and very large antennas. The Space Station will be used for the development of new equipment, as well as multiple OTV use for boost of very large platforms.

COMMERCIAL COMMUNICATIONS

Business opportunities

- Satellite placement *
- Satellite assembly & checkout in LEO*
- Satellite servicing & repair *
- Protected satellite stowage at LEO *

Missions to support opportunities

- Equipment development
- Assembly of very large satellites
- OTV boost to GEO
- OTV supported servicing

***User positively identified**
Users require accurate cost data prior to commitment

15112793-14

The processing of materials in space represents a relatively new and expanding frontier for commercial applications. A number of business opportunities were confirmed through personal and telephone contacts during the first phase of the study program. In particular, a potential for future space business was identified in the area of investigation of new alloys under zero g conditions, the growth of high purity crystals, the manufacture of pharmaceuticals, and the formation of glass and ceramics in space. Contacts with INCO of Suffern, N.Y., GTI of San Diego, CA, Monsanto of St. Peters, MO, and Johnson & Johnson of New Brunswick, N.J. showed moderate to high interest in these opportunities.

To support these business opportunities, complimentary efforts will be needed to support the research, process development, and production of space manufactured materials.

COMMERCIAL MATERIALS PROCESSING

Business opportunities

- Investigate new alloys *
- Crystal growing *
- Pharmaceuticals *
- Glass & ceramics

Missions to support opportunities

- Research
- Process development
- Production

***User interests positively identified**

15112793-12

We have received our first input from the ERNO study of Space Station users. The data is summarized in three areas:

Space Processing

Life Science, principally Human Physiology

Operations Support, e.g. Assembly of Large Structures and Cryogenic Fluid Transfer

They state that, similar to our experience, "commercial users are very restrained to invest in space utilization in the near future".

Although the data received provides general statements and trends, we expect to receive additional details later. The categories of materials processing are similar to those that we have defined and provided for accommodating in our Materials Processing Lab requirements. The European interests appear to be a follow-on to their planned Spacelab activities.

EUROPEAN USER INTERESTS
SPACE PROCESSING

Metals/composites

- Solidification of metal melts
- Solidification of metal melts with finely dispersed additives
- Measurement of physical parameters
- Technology improvement/advancement studies

Crystals

- Basic study of melt zone crystal growth
- Growth of new types of semiconductors with solution zone process
- Growth of monocrystals with finely dispersed inclusions
- Growth of crystals by precipitation from solution

Interface & transport phenomena

- Basic study of cellular convection
- Basic study of marangone convection
- Studies of transport phenomena at & in interfaces/surfaces
- Measurement of transport parameters

Physical chemistry/process engineering

- Measurement of thermal & caloric state functions at the critical point
- Studies on reaction kinetics at interfaces
- Study on reaction kinetics in gases & liquid
- Measurement of physical parameters

Pharma-/bioprocessing

15112793-165

Not all firms who responded provided specifics on potential commercial missions. The defined missions cover a range from research-type such as chemical reaction effects in microgravity to MPS production and monitoring the earth's atmosphere for pollution. Johnson and Johnson indicated their well-known efforts in electrophoresis but declined to provide detailed information because of their affiliation with McDonnell Douglas. Because it is an important space mission, we continue to carry it as a positive response.

The industry responses for economic factors show that their estimated investment levels toward Space Station utilization are predominantly less than one or one-to-ten million dollars. Their estimated investment horizon for Space Station related ventures are principally in the 5-10 year range. They characterized the risk associated with such ventures as fairly great.

In regards to the potential benefit of a Space Station to their activities for reducing costs are heavy on the low side with a lot of "unknown" replies. Their estimates of the industrial value of a Space Station were mixed.

Of interest was the responses to the question, to what degree has the possible availability of a manned Space Station influenced the company's planning for the next 20 years. The answers were heavily "no influence". The second question asked how this would change after receiving our User Brochure. The indications were generally a moderate increase in influence.

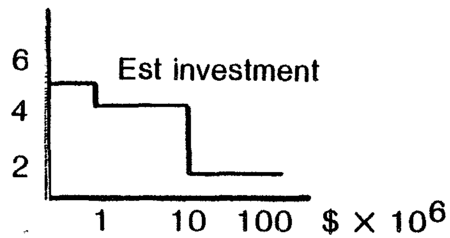
Although the sample is small, these responses were from firms who had sufficient interest to fill out and return part or all of our User Fact Sheet.

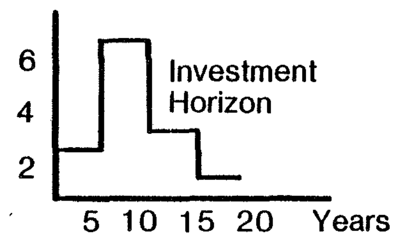
COMMERCIAL USER RESPONSES

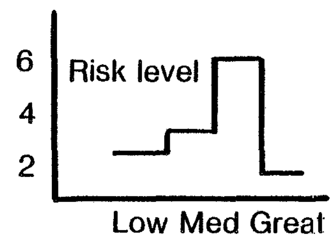
Missions

- Enzymes from fermentation
- Metal alloys (2)
- Silicon crystal growth
- Electrophoresis (details available through MDAC)
- Atmosphere sensing
- Chemical reaction effects
- Gamma ray astronomy
- Electronic equipment hardening
- Communication satellites launch/service

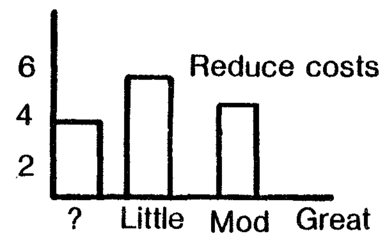
Ecomonic factors

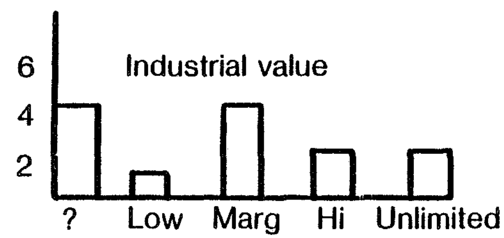




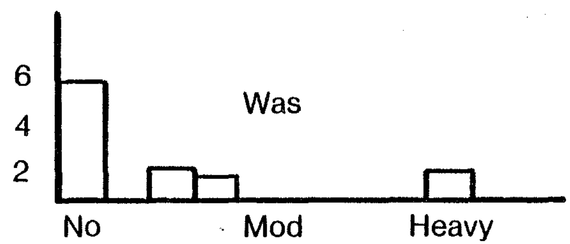


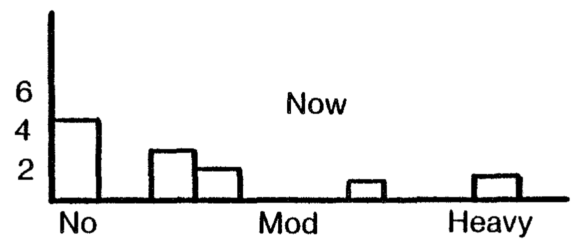
Space station potential benefit





Planning factors — (S/S influence on 20 yr planning)





The data received to date is very positive from the communication satellite sector. There are strong signs of interest in MPS and more limited in the earth/ocean observations sectors. We feel that although present planning is somewhat inhibited by the perceived barriers, a stronger reason for the limited interests may be due to the basic nature of businesses. For example, if one had conducted a similar study in 1885 or even 1903 about the planned uses for the new transportation system called airplanes, a similar result would have been obtained.

We feel the potential market exists and can be developed, but it will take additional time. Furthermore, once a Space Station is in being, the activities therein will generate uses and users that are not or cannot be forseen at this time.

COMMERCIAL APPLICATIONS
Preliminary Conclusions

Communication satellite placement market exists
- OTV an economic alternative to current launch systems

Commercial communications satellite servicing a viable mission

MPS & Earth observation markets exist but need development
- Planning somewhat inhibited by perceived barriers
  - — Relatively long ROI horizons
  - — Space station some distance in future
  - — Space operations are costly

Market potential & interests exist
- Additional time & detailed discussions required to expand beyond currently identified level
- An in-place facility will generate uses that may not surface during advanced appraisals

Special incentives may be required to induce commercial firms to increase research investments

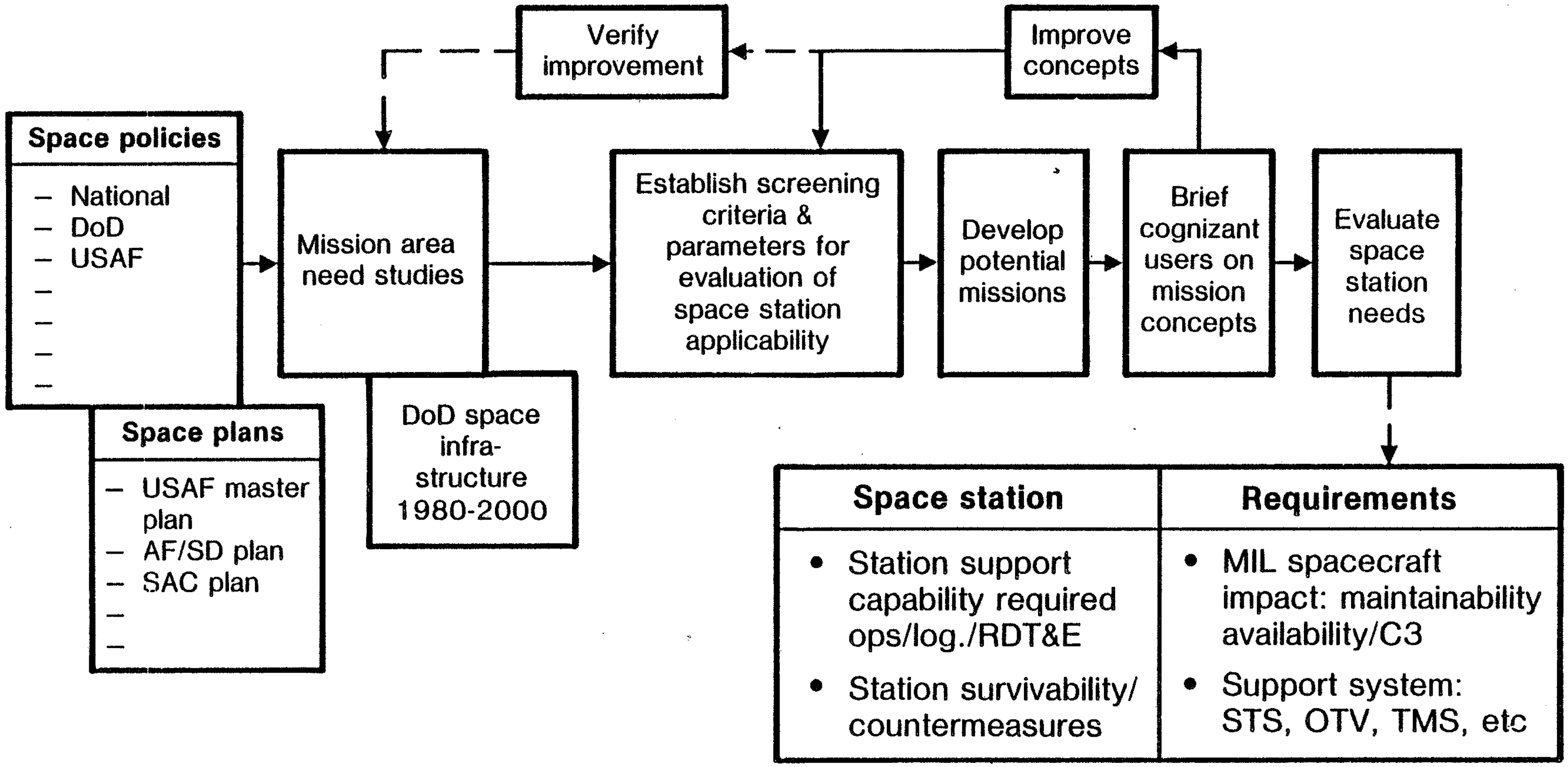
15112793-21

The goal of the DoD studies is to generate time-phased requirements for the Space Station Program based on DoD needs and the interaction of the Station Program with the DoD Space Infrastructure. DoD does not yet have firm general plans for the 1990 to 2000 period. We are using a "top down" approach, starting with National Policy statements, to synthesize our best view of the potential infrastructure. This will be the basis for evaluating impact of the Space Station Program.

A key element in the process is the continual improvement of our concepts through feedback from appropriate government agencies, in particular the military user community.

We started review of top level documents well prior to this study. We will continue as new policy planning documents are released and existing ones are updated. At this midterm point, we have started the user-community reviews and have already received useful guidelines from SAC, TAC and others. This cycle will include Navy and Army users along with the more obvious need for USAF feedback.

DoD STUDY FLOW



15112793-139

This figure and the following figure summarize a preliminary screening of the potential for a military Space Station to augment or enhance DoD space missions in the 1990-2000 time period. Mission areas derived from AF/SD Military Space Systems Technology Model (MSSTM) were examined to determine whether or not a single station in LEO could meet the coverage requirements implied by the mission and exploit man-in-the-loop in mission operations.

OPERATIONAL CONCEPT DEVELOPMENT

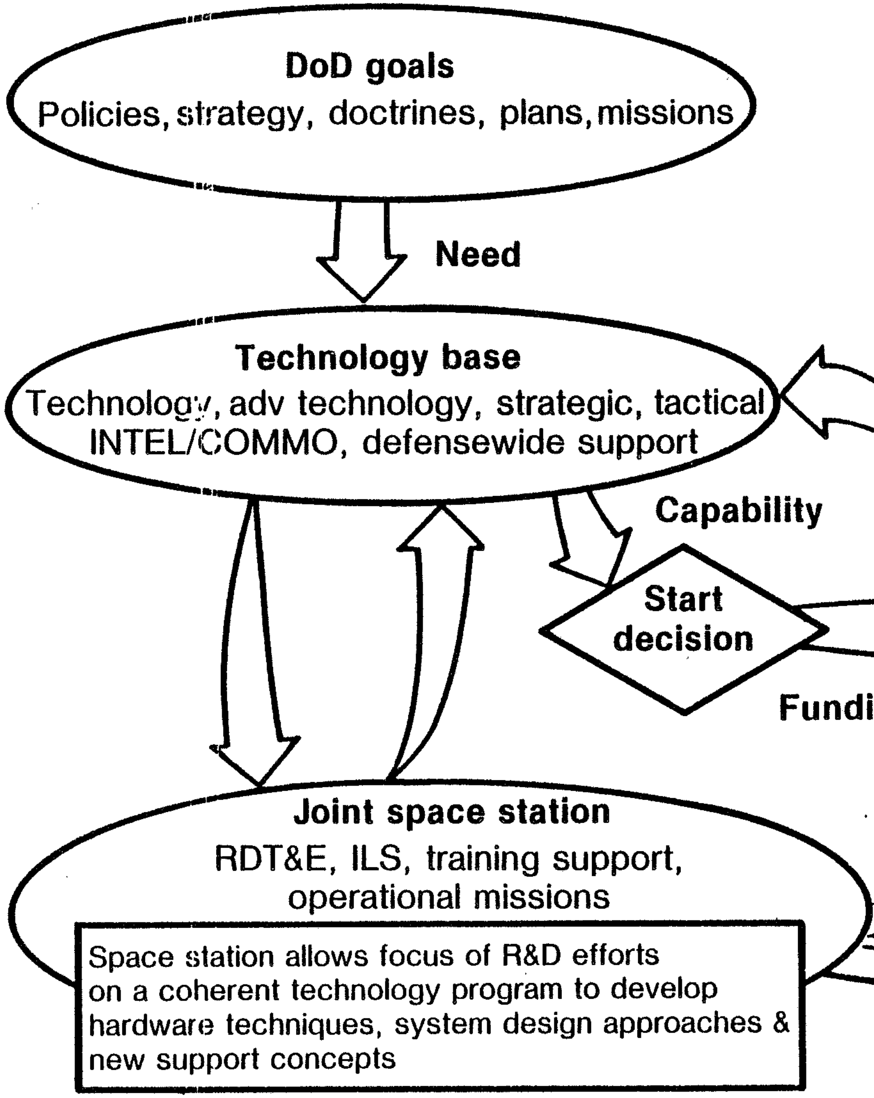
- Define all DoD mission areas (MSSTM)
- Apply screening criteria for space station applicability
    - Station at LEO
    - Single station meets need
    - Exploits man-in-the-loop
- Develop example, realistic concepts

15112793-136

The MSSTM derived military space functions, shown on the left of the figure, are all-inclusive and broad enough to cover support to a number of military missions. The screening criteria were applied to these functional areas to define specific mission applications as described under the heading selected concept. Six operational concepts were derived by this process, expanded and used as a basis for initial contacts with the DoD community, including potential users. In examining potential operational mission applications, it became evident that logistic support across most mission areas could benefit from a manned platform. The advantages of a LEO platform to serve as a base for a reusable space-based OTV is covered in detail in other parts of this briefing. Other logistics operations are possible, however, and an additional four concepts were developed as noted in the figure.

RDT&E "FORCE" MULTIPLICATION

"Current schedule and concurrency pressures leave no room for experimentation within individual weapon programs"
OSD, September 23, 1980



15112793-138

The Global Positioning System (NAVSTAR) provides an interesting retrospective case-history for use of a Space Station for RDT&E. GPS technology included the first use of L-Band, spread spectrum communications techniques from space, precision in ephemeris deterioration not previously demanded, and operation of precision clocks in the space environment. The best available RDT&E program construction was used.

Had a Space Station been available,a systematic, progressive RDT&E program would have allowed proof of the technologies, shortening the development cycle, even in areas such as the relativistic connections where prior analysis did, in fact, prove to be accurate. The value of in-place testing of technologies and subsystems, by permitting highly instrumented monitoring and recovery of "failed" items for examination, and diagnosis does not need to be emphasized. We believe that a detailed review of the GPS development history would show major schedule shrinkage and earlier, more positive passage of critical developmental and decision points.

While the GPS development is already history, each new high technology space program will offer new problems. An RDT&E station could offer the same kind of systematic proof of concept, technology and design.

GPS . . . WHAT IF

Problem Areas	Actual Approach	With Space Station
Ionospheric/atmospheric effect at L-band: Fade margins, etc Spread spectrum/codes	Free-fly test Piggyback NTS-1/2, NDSs	Systematic, controlled data development prior to free flight to ascertain effects on signal
Relativistic corrections	Theoretical analysis	Systematic proof of analysis prior to free flight
Radiation effects on memories	"Ad hoc" treatment	Systematic problem disclosure, diagnosis, test of solutions, least cost solution, clock reliability/ integration/thermal control
Clock stability		
Clock reliability		

Implications

- GPS was/is an advanced, high technology program
- Development would have been greatly enhanced by space station capability
- There will be more high tech programs: GPS follow-on, weapons, C^3I, training
- Space station availability will offer similar benefits
- No need to build in "guessing" inefficiency

Benefits of a space station

- Systematically eliminate technical uncertainties before major commitment of nonrecoverable assets in space:
  - — Early/positive discovery/diagnosis/solutions
  - — High confidence of success — least risk
  - — Reduce overall program schedule/cost
  - — Minimize impact of failures

We have chosen to separate the transportation function from the general integrated Logistics System concepts because of particularly appropriate application of the Space Station as a space-base for LEO to GEO (or other high energy) orbit transfers. We have addressed the specific benefits to DoD and all GEO users of such an orbit transport system, which could have early availability.

The station also has strong potential for ILS support of operational military space systems, both those based on the station and those otherwise independent. Full advantage of the station's potential demands (as it does for all systems) early integration of support concepts into subsystem and system design. Because of this we see full implementation of integrated logistics functions as a later time period application. Some specific preliminary concepts have been developed.

LOGISTICS

Transportation — LEO to GEO OTV payloads

- Midperiod IOC
- Significant cost benefits
- Economies of scale from joint program

ILS for operational systems

- Late period
- Station facilities for
  - — Docking
  - — Payload handling
  - — Subsystem maintenance
    - Diagnostics
    - Repair/replace
    - Checkout
  - — Spares stockage
- Free-fly space systems designed for compatibility
- Benefits in cost, availability, responsiveness

15112793-133

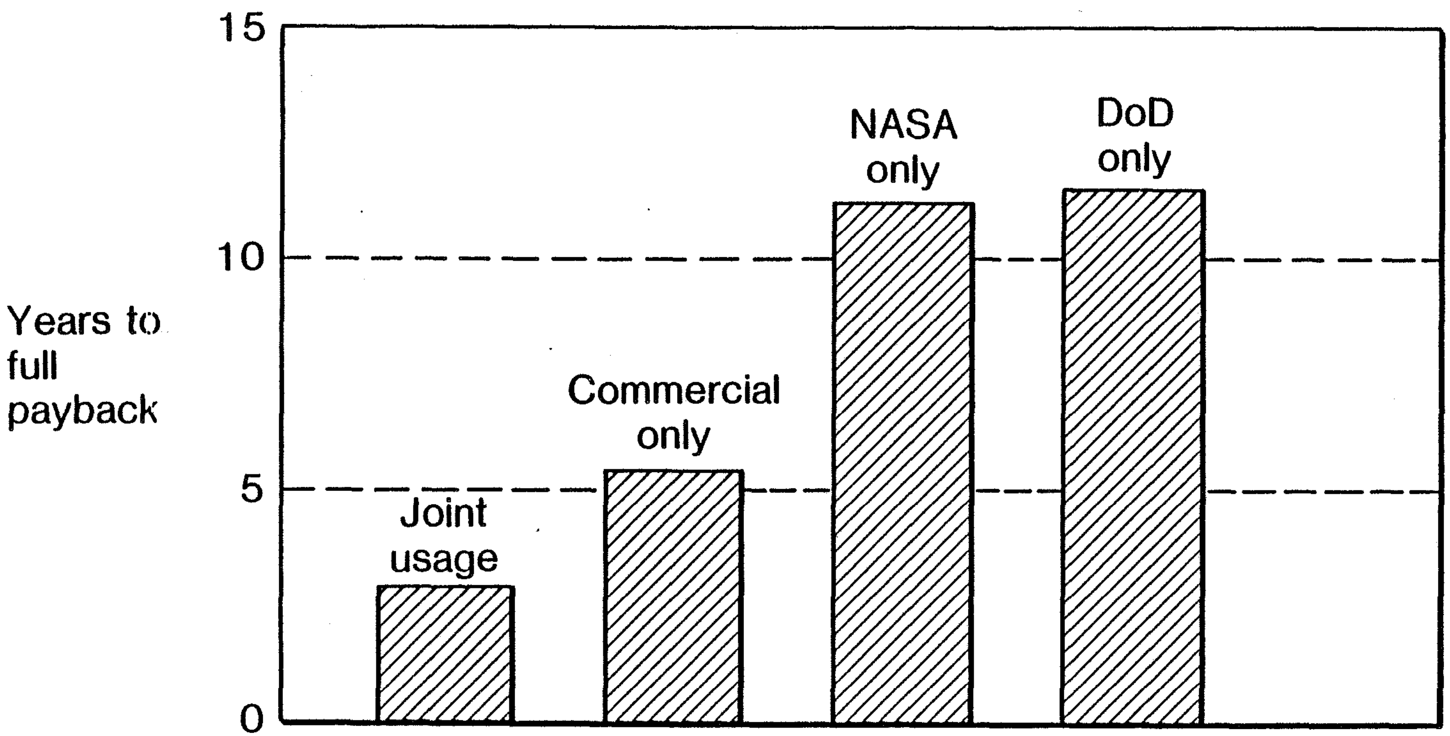
We have assessed the economic benefits of a Station-based Orbit Transfer Vehicle, an unmanned, recoverable system for transport of payloads from LEO to high energy orbits. The STS provides transportation from ground to the station at LEO.

The non-recurring cost to develop a LEO station and OTV system is about $3.7 Billion. We estimate that the OTV can provide transportation at a savings of about $5,000 per pound compared to an expendable ground-based system. The bar chart shows how these savings can pay back the non-recurring costs for DoD and NASA, and Commercial users (the OTV is equally applicable to all users).

The estimates are based on a Convair-generated payload traffic model compiled from several government sources, and totalling about 250,000 pounds per year to high energy orbits.

Joint usage compounds the savings compared to any of the potential users alone. A pay-back time of less than three years can be attained by general, joint use. NASA or DoD use only provides pay-back at about 11 years. Combined NASA/DoD use (excluding commercial users) pays back at about 5½ years. The enormous payoff for joint use is obvious.

STATION-BASED OTV BENEFITS



- 1995 OTV IOC
- High traffic model
- OTV recurring cost savings are $5K/lb
- Savings are relative to ground-based expendables
- Space station & OTV RDT&E = $3.7 billion
- To high energy orbits

15112793-140

The survivability area will have its greatest emphasis in the later part of the study. At this point we can summarize our findings at the two ends of the Space Station Program. We believe that the early station implementation will have an RDT&E emphasis and present virtually no threat to the enemy. While internal security requires considerable attention, implementation of survivability measures will not be required. When the station program is performing or supporting operational functions, it becomes a threat to the enemy commensurate with their perception of the particular functions. A number of technologies will be available to reduce vulnerability of these later systems, as shown. We anticipate that "maneuver on attack" is a key element supported by implementation of virtually all other available technologies compound the threat's problem and assure survivable, enduring systems.

We have also taken a preliminary look at the contribution a station might make to protection of other DoD space assets. We believe that station-based command and control of total space countermeasures offers significant benefit and have prepared an operational concept for this function.

PROGRESSIVE SURVIVABILITY REQUIREMENTS

Station with RDT&E emphasis

- Non-threat to enemy
- Not a strategic target: used for science experiment, RDT&E, commercial
- Normal security/ environmental protection/controls
  - Procedural controls
  - Limited surveillance
  - Secure data links
  - Safety provisions

Station with operational emphasis

- Hostile to enemy
- Strategic high priority targets
- Normal security/environ. protection/control plus
  - NBC protection
  - Graceful degradation techs
  - Maneuver
  - Active protection devices
  - Network/cellular concepts
  - ECM/ECCM
  - Protection of routes

Several facts emerge from an evaluation of generic operational mission requirements. They generally require GEO or high inclination orbits and often higher than LEO altitudes. Security and survivability requirements are key and often drivers. A basic conclusion is that dedicated, i.e., not joint with scientific/foreign users, facilities are required. Some missions require multiple positions in space and are probably free-flyers. Conflicting orbit and other requirements indicate that multiple facilities are likely.

DoD RDT&E missions are derived from operational missions and directly support their evolvement when considered as two sets - R&D and T&E, logical differences are evident. Verification T&E for operational missions either require or benefit from performance in the operational environment, in this case - orbit. On the other hand, R&D missions can usually be performed under different though comparable conditions and are candidates for a low inclination LEO orbit such as that determined for S&A and commercial missions. Furthermore, the survivability requirements become progressively lower progressing from operational to R&D. Security is less demanding also but still of concern. The conclusions are, therefore, that R&D activities are suitable for a LEO low inclination orbit, even in a joint station. Some T&E missions may be also but others will require operational missions.

Because the RDT&E missions are derived from operational missions and these are not well defined at this time, the detailed technical parameters of the RDT&E missions have not been developed at this time and do not appear in our data bank like those of science, applications and technology.

DoD INFLUENCES ON EARLY STATION REQUIREMENTS

Operational missions generally require dedicated prime facilities

- High inclination/high altitude orbits
- Security & survivability are key requirements
- Availability/responsiveness/effectiveness are of high importance
- Conflict requirements set basic mission needs
- Support/training may be providable from T&E "station"

Test & evaluation missions

- Verification T&E for operational missions generally require access to same orbits (high inclination/high altitude)
- Some activities may be suitable for LEO-joint station

Research & development missions

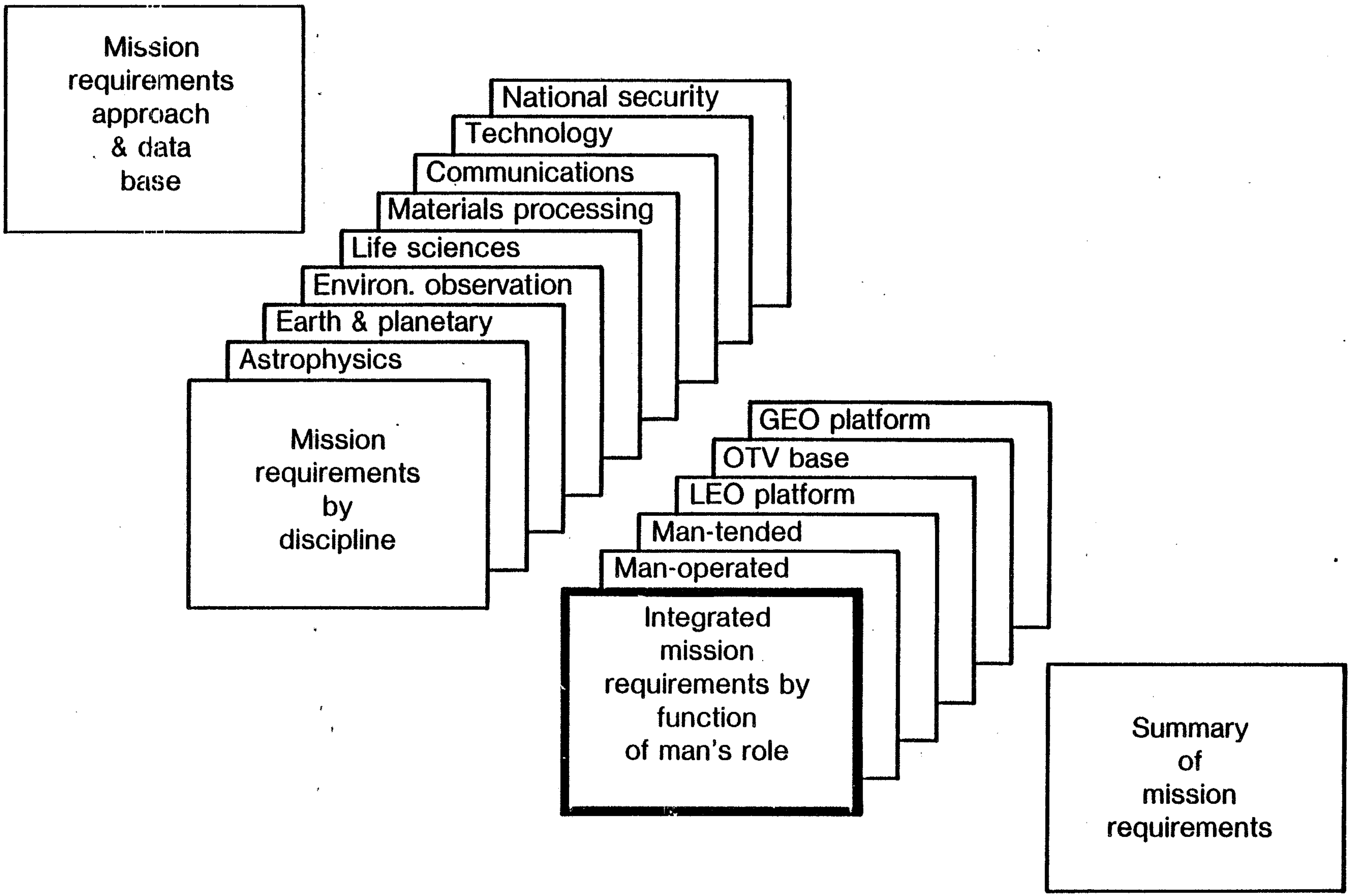
- Suitable for early joint station in LEO
- Security aspects of concern
- Survivability not an issue
- Some missions (e.g. Earth obs, commun) similar to S&A & commercial
- Helps define requirements for operational missions

Detailed mission technical requirements not developed at this time

Provided in this section are the results of the integration activity performed during the mission requirements task. As indicated during the description of our approach, the various mission requirements were sorted in accordance with the basic functions: Man-operated, Man-tended free-flyers, and OTV base.

In addition, an analysis was made of those missions which were candidates for LEO and GEO platforms.

After grouping by the above functions, an analysis was made to determine the key resource requirements, such as orbit, power, crew, data and physical size. These data provide information for the architectural studies.


Mission requirements approach & data base
National security
Technology
Communications
Materials processing
Life sciences
Environ. observation
Earth & planetary
Astrophysics
Mission requirements by discipline
GEO platform
OTV base
LEO platform
Man-tended
Man-operated
Integrated mission requirements by function of man's role
Summary of mission requirements

15112793-55

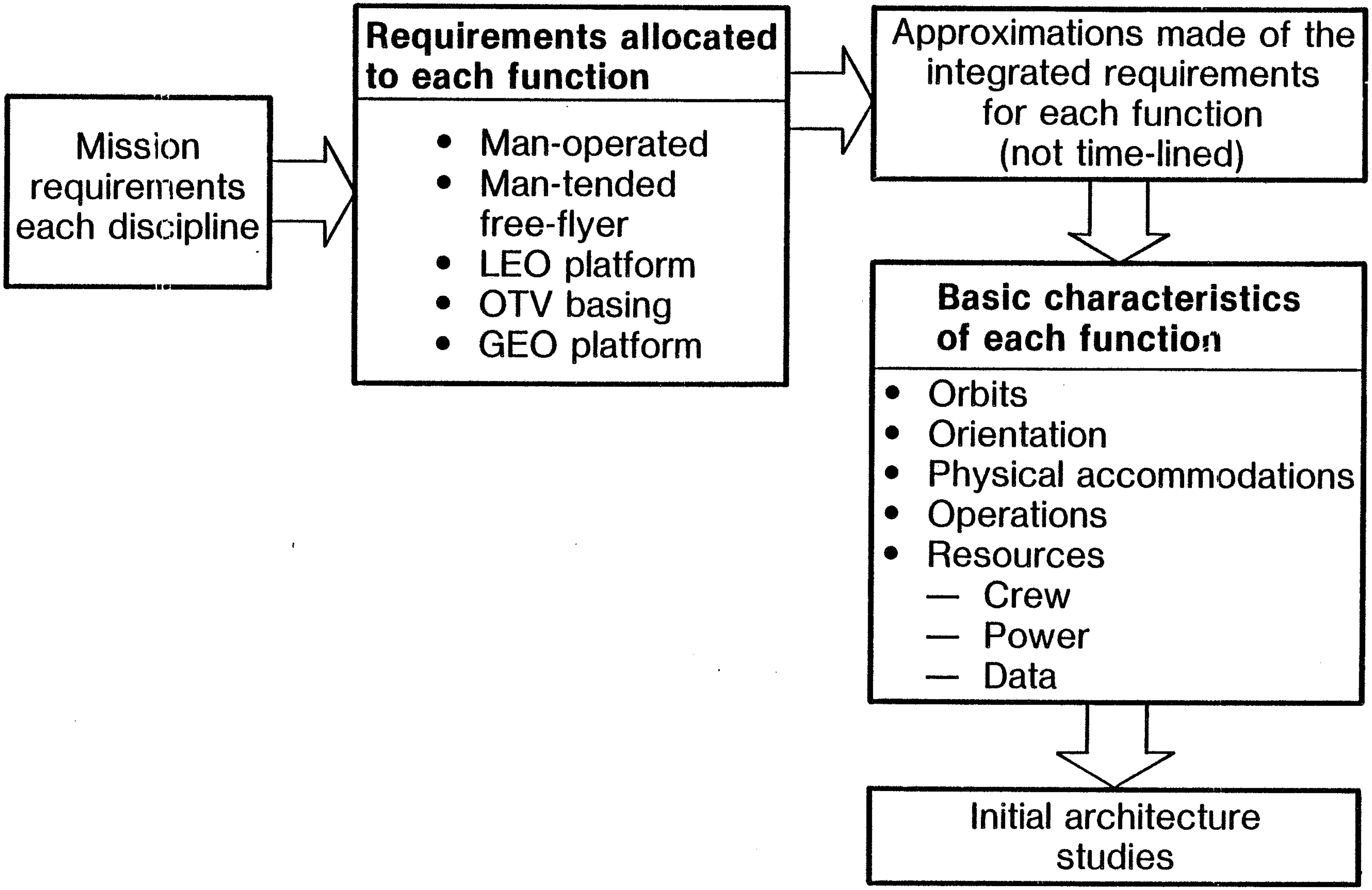
The requirements of each mission, for all the disciplines, have been allocated to the appropriate function of the Space Station system: man-operated, man-tended free-flyers, LEO platform, OTV basing and GEO platform.

A preliminary integration of each area has been made to facilitate an early start at deriving architectural options, and preliminary cost/benefit data. This was done to develop very approximate basic characteristics of each function, and was done prior to any overall function time-lining being accomplished.

To accomplish this preliminary integration, the requirements allocated to each function were reviewed. From this review, an approximate level for each resource was estimated and the general physical characteristics were identified for the major elements of mission equipment to be accommodated, serviced, or transported within the space system.

During the second phase of the study, a more detailed integration analysis will be conducted to more closely define the integrated mission requirements and characteristics for each function.

INTEGRATION OF MISSION REQUIREMENTS



15112793-160

Missions which require, or would significantly benefit from man's presence to conduct research activities, or to operated or control mission equipment while in LEO, are included in the man-operated function.

Man's role in the various types of man-operated missions include:

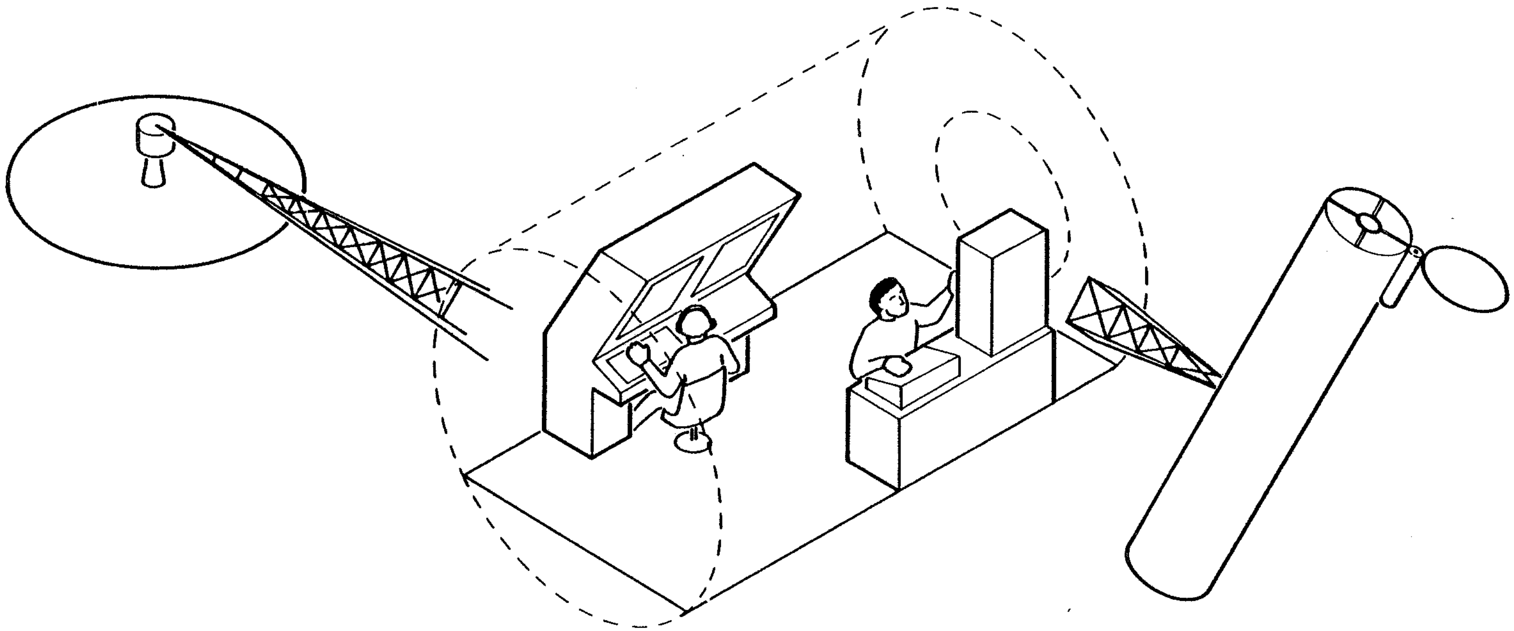
- Scientific research where man is required to directly conduct a research activity, observe results, and redirect or adjust conditions.

- Advanced technology development where man's presence is required to assemble large test structures, or can greatly enhance results, expedite development of new systems and techniques, with a minimum amount of automated equipment.

- Assembly, checkout/calibration, and servicing of very large observatories in LEO prior to commitment to a free-flying mode, where man's capability can be exploited to accomplish operations that are costly to automate or to control from a remote location.

These missions are accomplished with the necessary laboratories being either an integral part of the Space Station, or attached directly to it.

MAN-OPERATED FUNCTION



Missions accomplished by station crew

- Conduct of research in microgravity
- Development of sensor systems for operational use
- Assembly checkout & calibration of very large observatories
- Operation of observing & sensing systems in station attached mode

15112793-30

Missions for the man-operated function comprise activities in all of the disciplines concerned with Space Station activities. These include research and technology development in the log "g" environment of LEO, observations from above the filtering of the earth's atmosphere, and observations of the earth's surface and atmosphere from the vantage point of LEO.

These missions represent requirements for a range of orbital inclinations, with all being satisfied by an orbital altitude of 400 to 500 km. The orbital inclination requirements generally fall into one of three groups, dependent on mission objectives:

- Missions conducting R&D in low "g" or viewing above the earth's atmosphere, are not sensitive to orbit inclination and can be satisfied by the 28.5° inclination most efficiently for Shuttle launching.

- Earth viewing missions desiring a high latitude either to provide adequate coverage of the earth or to operate in a preferred position relative to the Van Allen belts, can be largely satisfied by the maximum 57° inclination orbit possible from KSC, with most missions having a preference for a polar orbit when possible.

- Viewing missions requiring global coverage by operating in a 90° polar orbit.

A number of the missions project a requirement for early operation at a lower inclination orbit, with later relocation to higher inclination or polar orbit for completion of mission objectives.

TYPICAL MISSIONS — MAN-OPERATED FUNCTION
LEO — 400-500 km
Includes 28½, 57 & 90-deg Missions

Discipline	Title	Lab Functions
Astrophysics	Advanced X-ray astrophysics facility	Equipment checkout, maintain & update
	High res X & gamma-ray spectrometer	Attend focal plane — reduce data
	Very large space telescope	Assembly & checkout; potential opers
Earth & planetary	Geophysical investigation	Sensor & operations development
	SAMEX microwave exper	Conduct experiments
	Earth feature identification	Analysis techniques
Environ observ	Measure air pollution	Technology development
	Orbital LIDAR facility	Equipment evaluation/development
Life sciences	Vivarium & plant growth facility	Plant & animal research
	Controlled ecology life S/S	Equipment devel & implementation
Matls processing	Biological materials	Process development
	Crystal growth	Production
	Alloys/solidification	Research
Communication	Large deployable antennas	Equip development & assembly operations
	Increased commun sat. capability	Improve EIRP & alternate; new freq exper
Technology	Large structure experiments	Tool, equip & technique develop
	Laser to elec energy conversion	Experiments & equipment development

15112793-92

The orbit requirements of the man operated function of the 82 potential missions that have been identified will have a significant impact on Space Station orbit selection. For example, in the Astrophysics discipline the principal driving requirement is a low altitude, low inclined orbit which provides a low radiation environment for the sensors. The desired orbits are shown, however it is expected that additional review will show that the orbit parameters can be expanded above and below those desired.

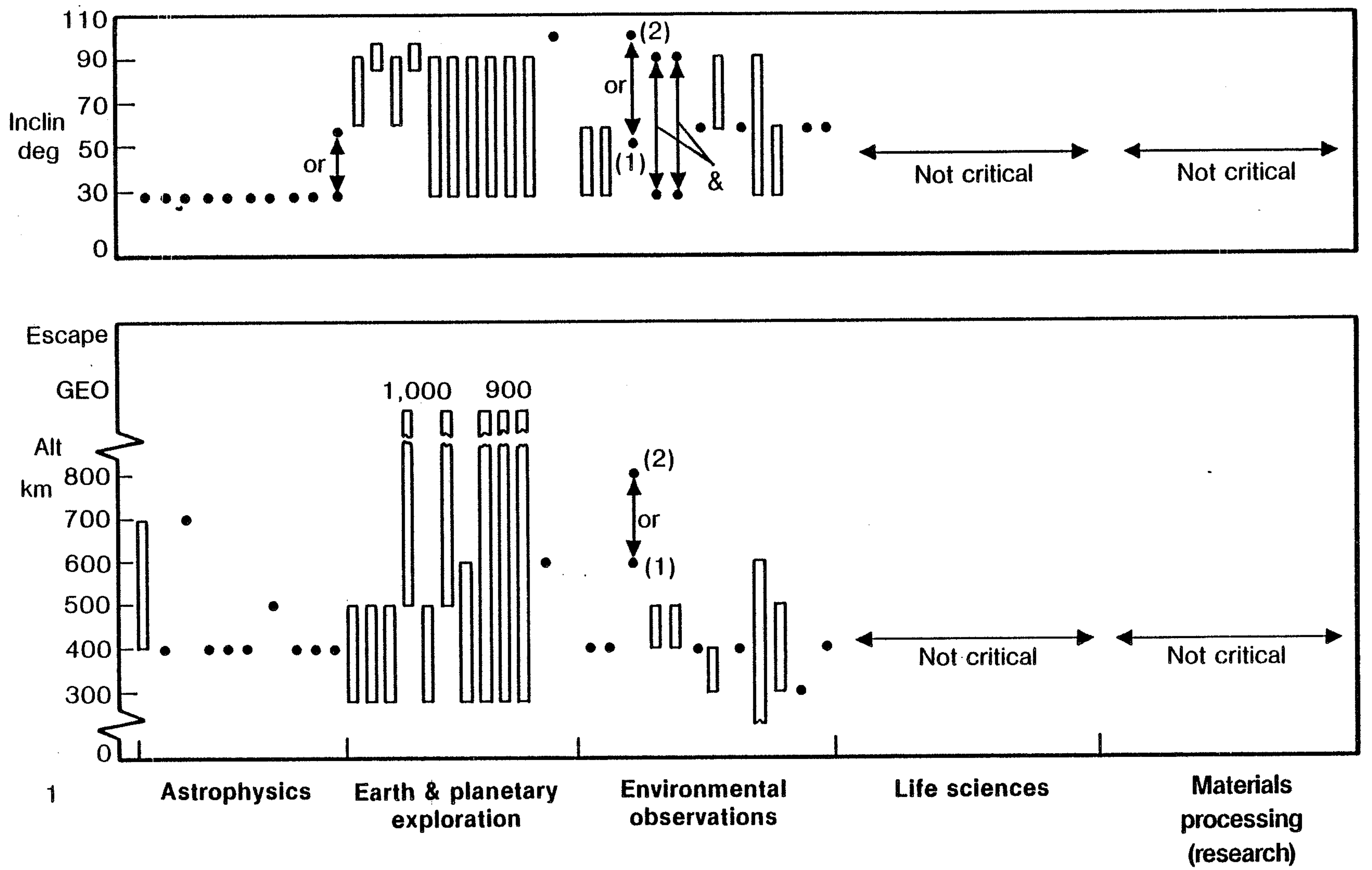
On the other hand, the Earth and Planetary Exploration missions have more flexibility since their primary mission in the man operated function is to develop sensors and techniques for later use on free flyers in specific higher inclined orbits that provide global coverage. This flexibility is also generally true for Environmental Observations. Some missions have more than one discrete preferred or required orbit.

For Life Sciences and Materials Processing the orbits are not critical so long as the acceleration level is within acceptable limits.

The Communications (i.e., LEO experiments) and most of the Technology Development missions, are insensitive to orbit parameters. The range of National Security orbit parameters in the R&D activity is sufficiently broad so as not to be critical for joint use with NASA and commercial users.

In summary, the orbit requirements for the man operation function in a Space Station can be selected to be compatible with Shuttle delivery capability. A 28.5°, 400-500 km orbit is satisfactory for all but a few missions.

ORBIT REQUIREMENTS
Man-Operated Function



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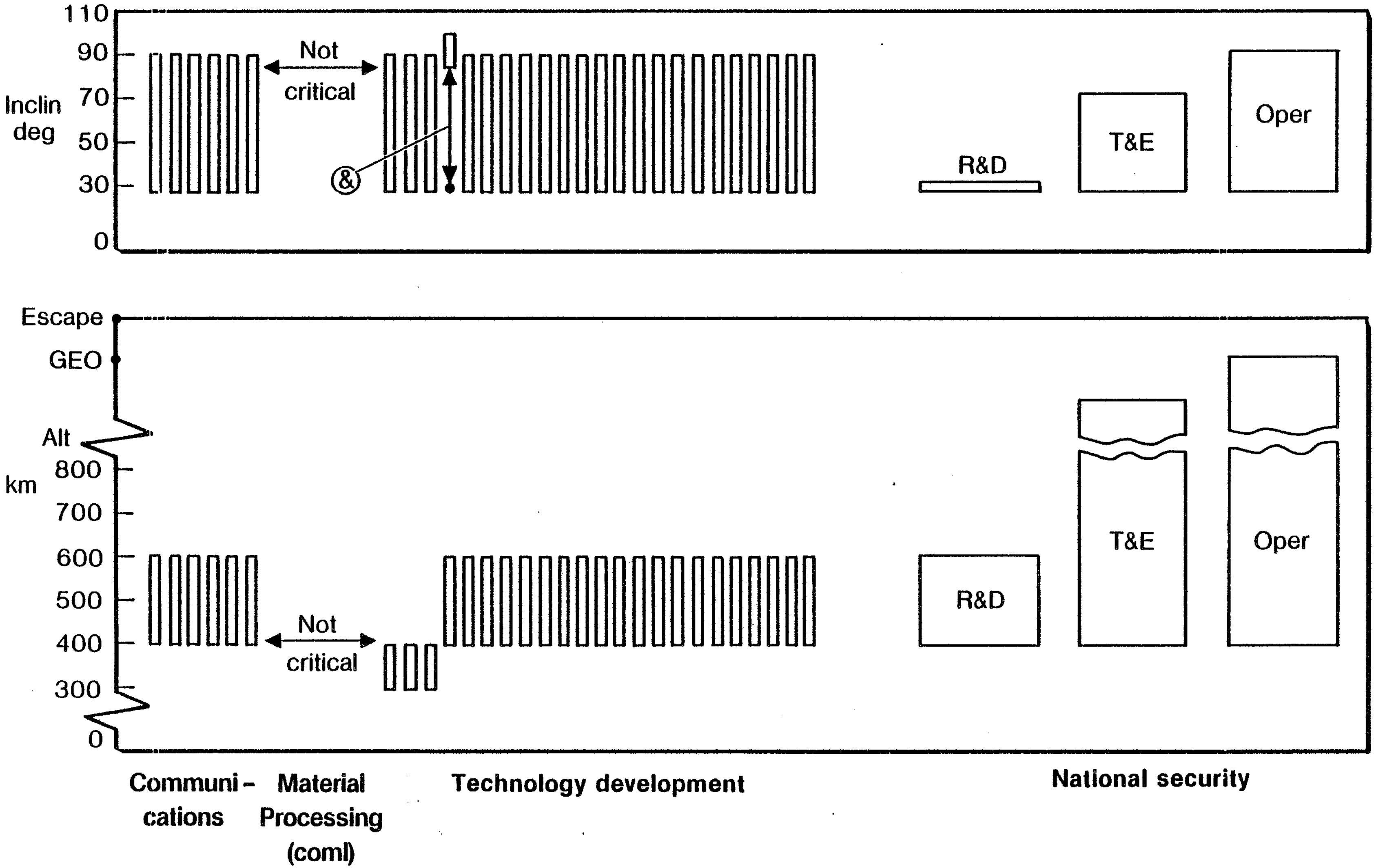
ORBIT REQUIREMENTS
Man-Operated Function
(continued)



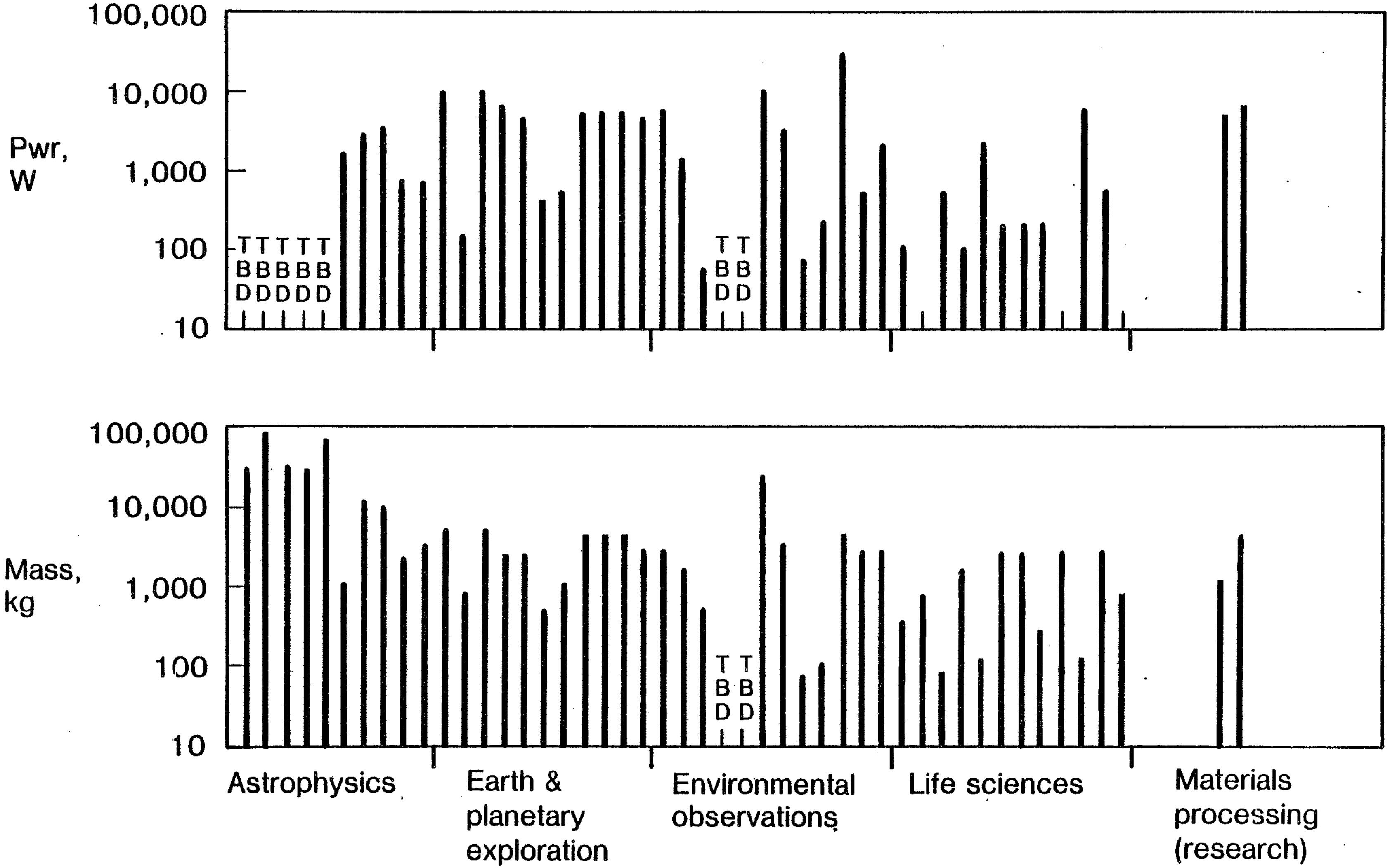
15112793-115

The mass of most of the missions for which estimates have been made are well within the nominal capability of the space shuttle element of the Space Transportation System. However, some equipment for Astrophysics and Environmental Observations individual missions is heavy enough to fully load a shuttle flight, and some will require more than one shuttle flight. For example, 2 of the missions for Astrophysics (nearly 100,000 kg each) will probably require 3 or 4 flights each. Some Technology Development Missions, when fully defined, are also expected to require multiple flights to implement.

Most of the missions require less than 10 kw of electrical power to operate. However, the LIDAR mission requires 25 kw and two missions in Material Processing (Commercial) require significantly more power, e.g. 30 and 65 kw respectively.

Further analysis of these requirements, including time phasing, is required to determine the impact on the Space Station architecture.

MASS & POWER REQUIREMENTS — MAN-OPERATED FUNCTION



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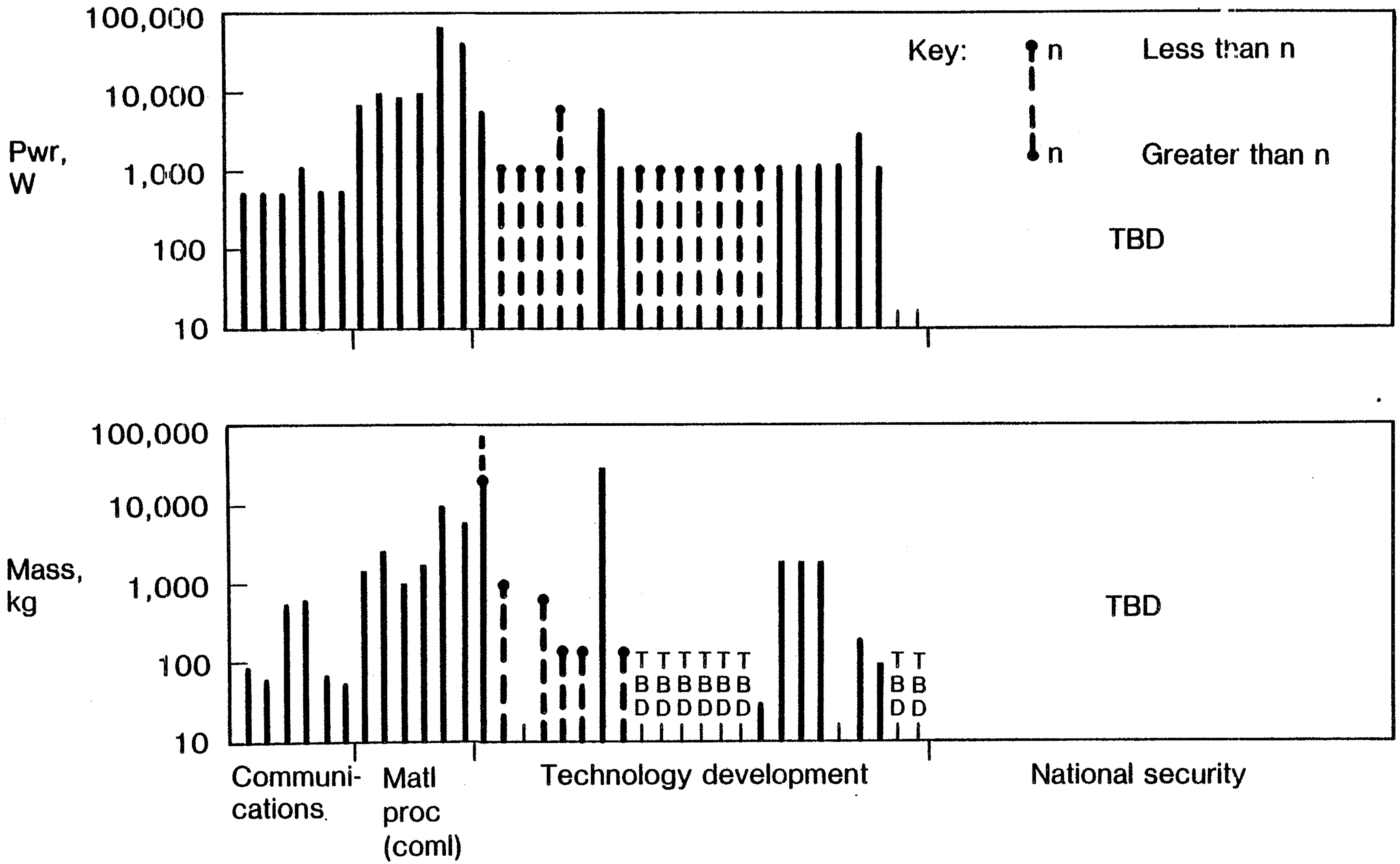
MASS & POWER REQUIREMENTS — MAN-OPERATED FUNCTION (continued)



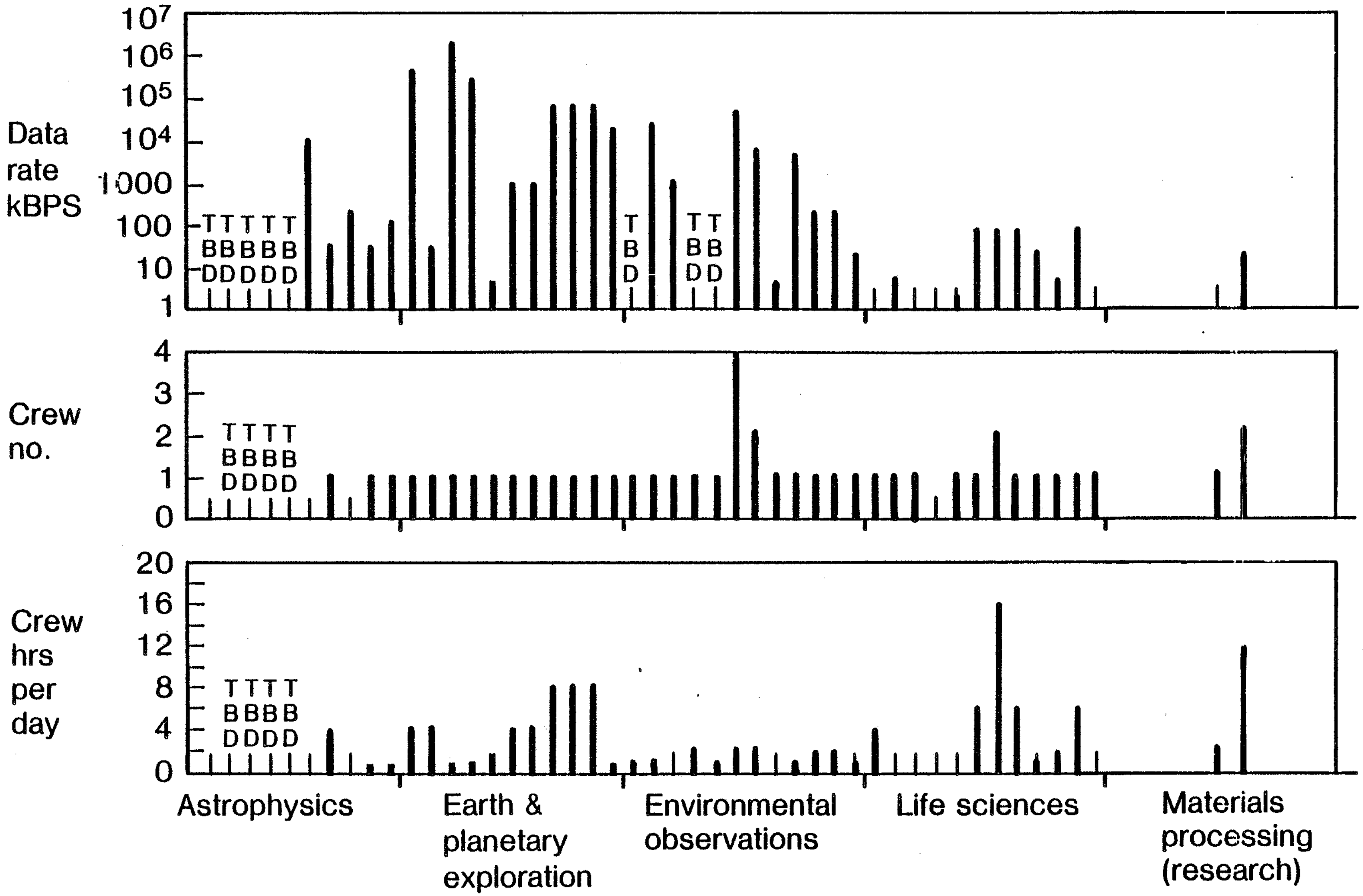
15112793-86

For those missions whose resources requirements have been estimated, the crew rate is nominally at about 2 to 4 man hours per day. In a few cases of Earth and Planetary Exploration, the requirements rise to 8 man hours per day, Material Processing (research) to 12 and Life Sciences to 16. For these latter missions, the number required in the crew to perform the function is 12 crewmen. One Environmental Observations mission, which includes many simultaneous experiments in plasma physics research, requires a crew of 4. However, the crew rate is quite low at 2 man hours per day. This low usage is based on the wide distribution of "targets/location of opportunity" along the orbit path. In the Technology Development discipline, several of the missions require a crew of 4 but only for initial setup, i.e., on a non-recurring basis.

The data rates in several of the disciplines are quite high, e.g. up in the megabit or even the gigabit per second (10^6 KB ps) range. These higher rates will no doubt require some type of preprocessing and evaluation which is of course one of the roles of man on the Space Station.

To bring into better focus how these resource requirements are to be integrated for the several missions, further analysis time phasing of the missions will be required.

RESOURCE REQUIREMENTS — MAN-OPERATED FUNCTION



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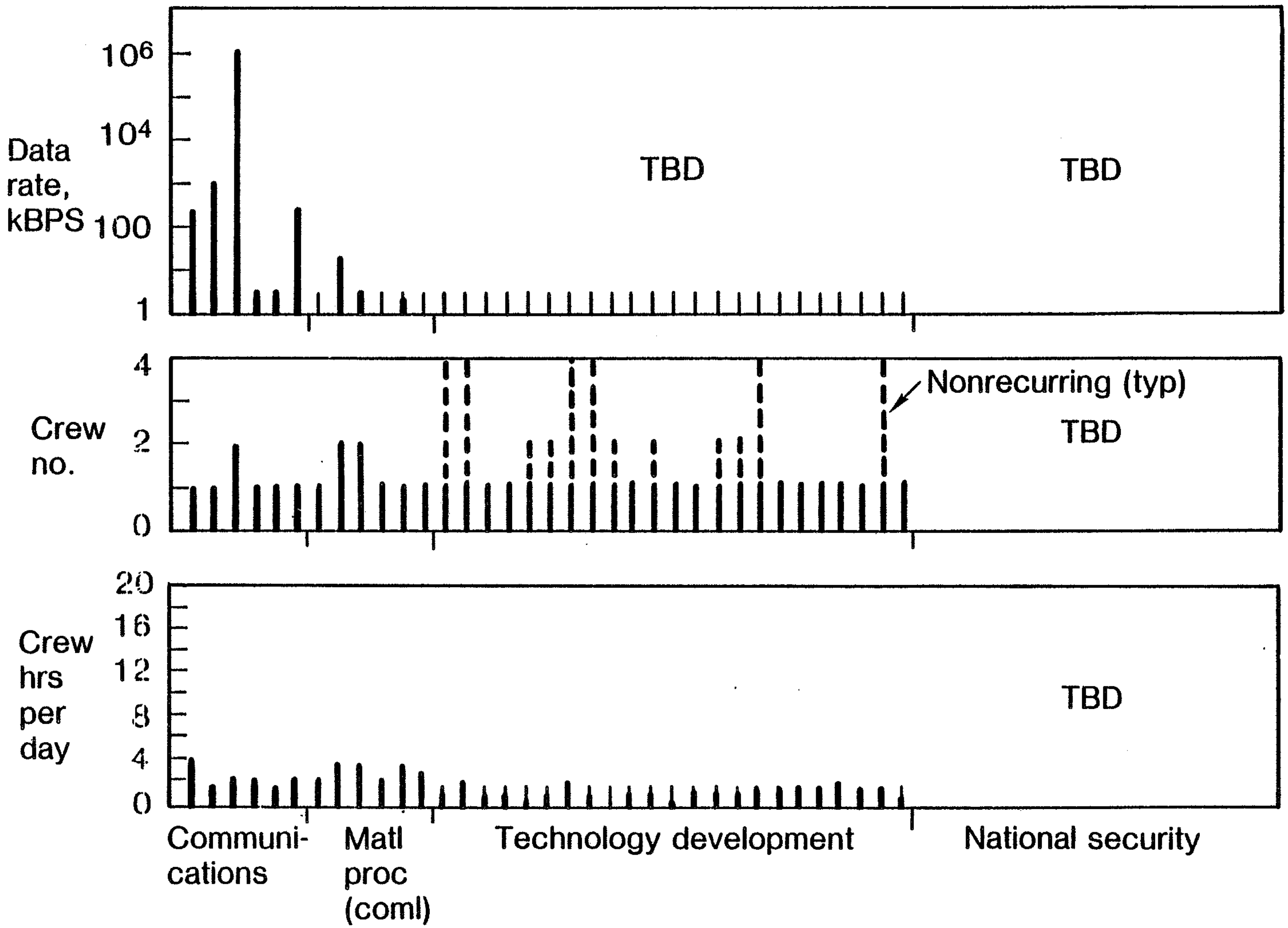
RESOURCE REQUIREMENTS — MAN-OPERATED FUNCTION (continued)



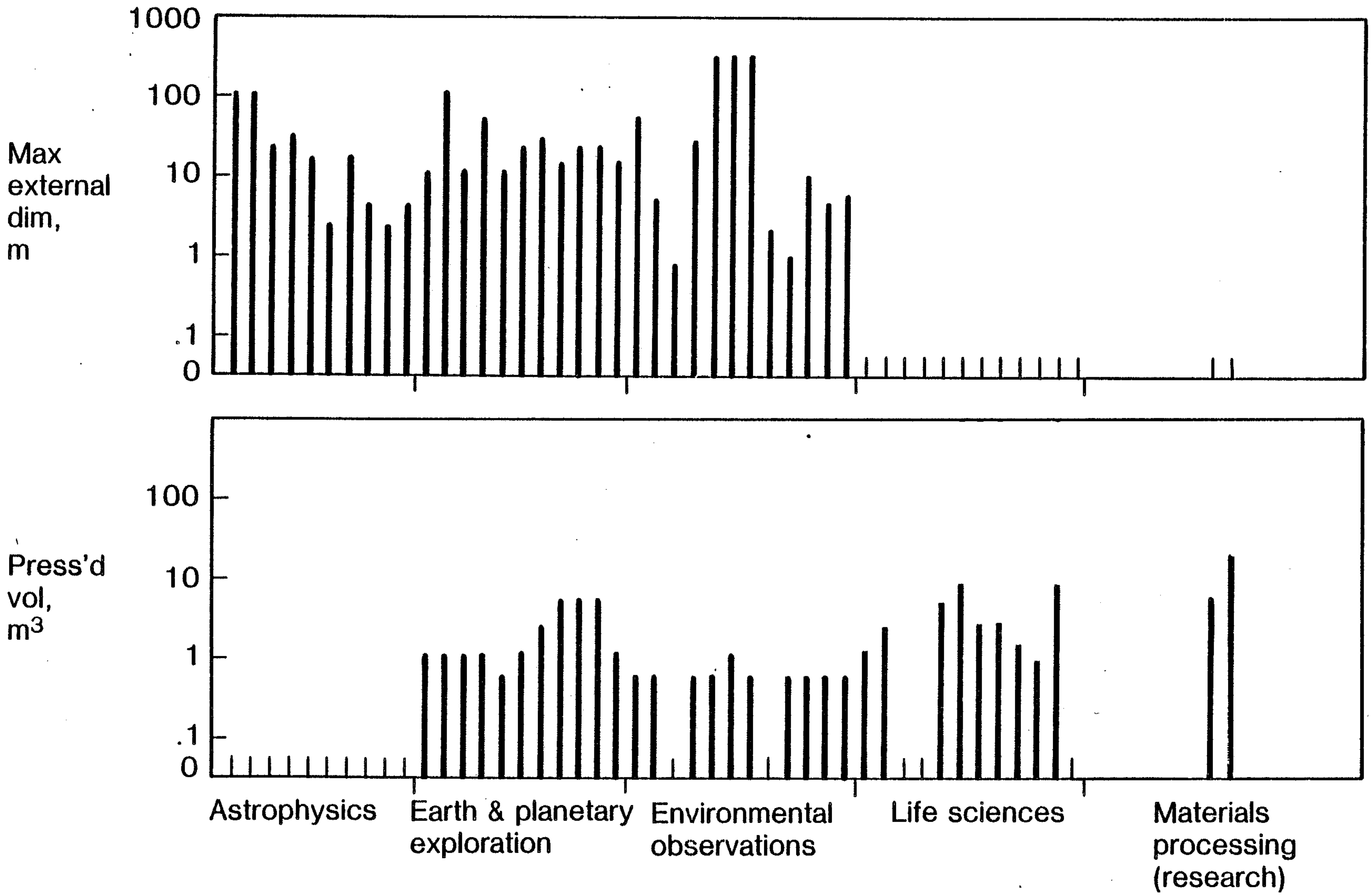
15112793-80

Preliminary estimates of size and pressurized volume required have been prepared for the various experiments and missions studied in connection with the Space Station. Size for each mission category is characterized in terms of a "maximum external dimension." This applies to the equipment as deployed in space and varies from a fraction of a meter to many kilometers. The larger sizes represent extensive structures, assembled and deployed in orbit, employing components delivered by several shuttle flights.

Pressurized volume is indicative of the controlled-environment space demands of the various experiments on board the station. The data given will eventually be useful in preliminary sizing of the Space Station. It should be noted that in many cases experiments are run sequentially in the same dedicated space. Care should be taken, therefore, not to think of total space required in terms of a summation of all the elements on the chart. Time phasing of the missions is required for determining the proper mix architecture and resulting pressurized volume for mission equipment in the station architecture.

The sizes and volumes shown give a feel for the overall scope of Space Station-related experiments under consideration. It is possible that prioritization will eventually modify this scope.

MAXIMUM SIZE & PRESSURIZED EQUIPMENT VOLUME — MAN-OPERATED FUNCTION



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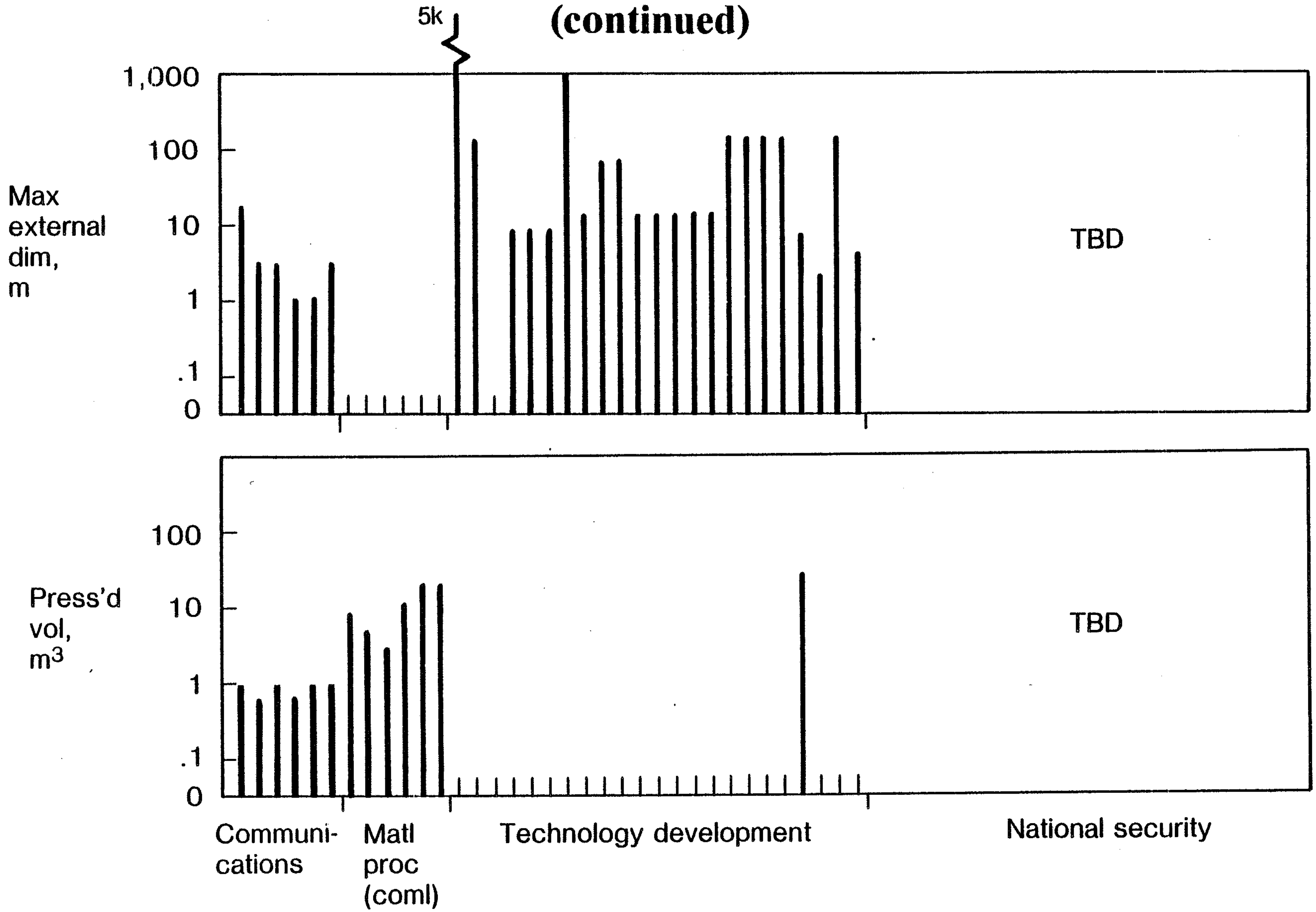
MAXIMUM SIZE & PRESSURIZED EQUIPMENT VOLUME — MAN-OPERATED FUNCTION (continued)

GENERAL DYNAMICS
Convair Division



15112793-81

There are special requirements within Space Station operation disciplines which could place extremely severe requirements if viewed separately, or when viewed in total, represent conflicting or compounded requirements. Most of the Astrophysics experiments require a contamination free environment. Engine fumes, for example, would contaminate a telescope lens. Telescopes also require a high stability and pointing accuracy which could not be achieved on a manned platform.

For earth observations, global coverage requires a high inclination orbit. Sensors require an orientation that provides continuous earth pointing, and some missions require that a sensor precisely repeats a previous ground tract at the same time of day.

Some planetary launches require a very high energy boost, which may exceed that capable with a Space Station based OTV, at least during the early years of OTV development. Other planetary missions will return a spacecraft to LEO which must be captured to retrieve and analyze a sample.

Environmental observations also require high pointing accuracy (but not as high as Astrophysics). Construction in orbit will be required to provide a long baseline (200-300m) antenna array and a high precision reflection surface.

Requirements for Life Science include a vivarium for plants and animals, as well as a dedicated medical clinic. A 0-1 g centrifuge must be provided for some experiments while a continuous low "g" conditions ($< 10^{-4}$) is required for others. Continuous low "g" conditions are also required for Material Processing in space, but are even more severe (10^{-4} to 10^{-6}).

For communications technology development, one of the most important experiments requires the construction of a large antenna ($>$ 30m) with high surface accuracy. To evaluate transmission in the millimeter wave band (30-300 GH_z), transmissions will have to be scheduled to evaluate the effects on the signals due to fog, rain, snow, and terrain.

SPECIAL REQUIREMENTS

Astrophysics

- Contamination free environment
- High pointing accuracy (.0005 arcsec)
- High stability (.00005 arcsec)

Earth observations

- Continuous Earth pointing
- Global coverage
- Precisely repeating ground tract

Planetary

- Need to capture a returning spacecraft for sample retrieval & analysis
- High orbit energy requirements

Environmental observations

- High pointing accuracy (2 arcsec)
- Long baseline antenna array (200-300m)
- High precision reflector surface construction in orbit

Life science

- Vivarium for plants & animals
- Dedicated medical clinic
- 0-1 g centrifuge for experiments
- Worst case low g conditions (5 x 10^{-5})

Material processing in space

- Continuous low g conditions (10^{-4} to 10^{-6})

Communications development

- Large antenna (>30m) construction in orbit
- Millimeter wave propagation through various atmospheric conditions

15112793-117

A preliminary summary has been made of the general requirements of the man-operated function to provide a starting point for the development of architectural options. This summary provides approximations of the integrated requirements governing the over-all size, performance levels, and relative activity for the Space Station accommodations involved. The actual requirements of this function will be developed by mission analysis/time-lines during the next phase.

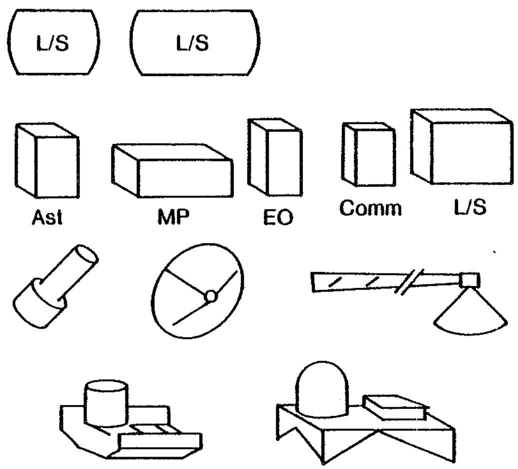
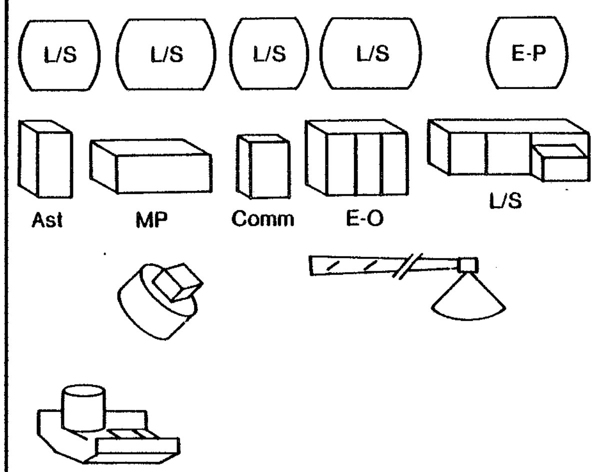
Requirements for the missions operating at 28½° inclination are summarized on the chart opposite; 57° and polar missions are summarized on the following page.

Mission equipment requirements include pressurized modules for research labs and control and data handling systems. External mounting provisions are required for very large sensors, antennae, and structural elements.

Crew size estimate is based on parallel operations of all missions considering task estimates, duration, frequency and skills required. Electrical power estimate considers equipment power levels and duration of usage, with Materials Processing as the main source of peak power required.

The major constraints of these missions are the sensitivity of low "g" research activities to local disturbances from crew activities, docking, etc., and sensitivity of many viewing sensors to contamination of the local atmosphere cabin leakage or other sources.

MAN-OPERATED FUNCTION
Summary — 28½-deg Inclination

Requirement	Initial Years	Final Years
Lab modules Equipment racks, cabinets, benches Sensor assys (typical) Sizes to 200 ml Mass to 4,000 kg		
Orbit — incl × alt Orientation	28½ deg × 400-500 km Inertial, Earth, celestial sensor point required	28½ deg × 400-500 km Inertial, Earth, celestial sensor pointing required
Operational	Logistics — 90 days On-orbit assy of sensors	Logistics — 90 days to 6 months On-orbit assy of large free-flyers
Crew-lab oper.	4 to 6 men Range of skills EVA required — assy; refurb	8 to 10 men Range of skills EVA required — assy; refurb
Power Avg Peak	~20 kW avg ~35 kW peak — 4-hr duration	~40 kW avg ~70 kW peak — 8-hr duration
Constraints	Gravity disturbance sensitive — life sciences & materials processing Contamination sensitive — astrophysics	

15112793-73

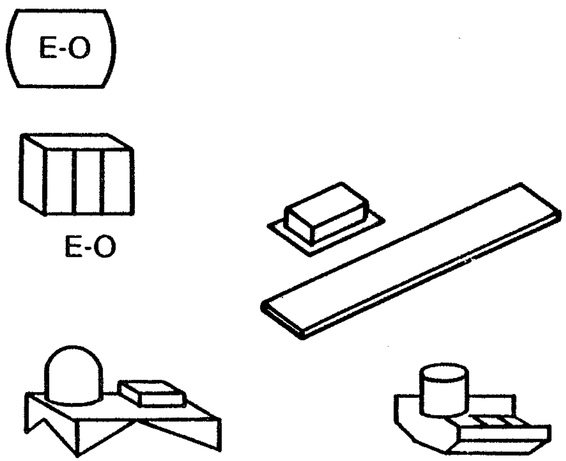
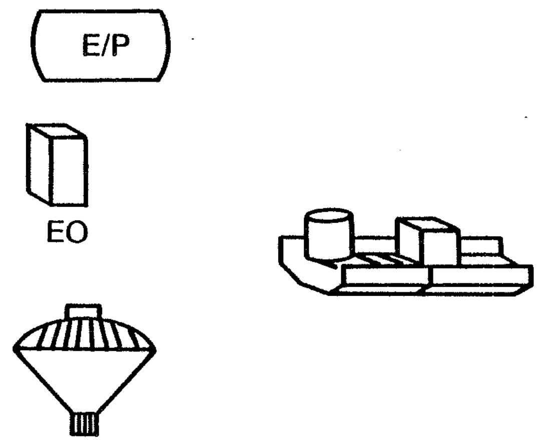
As discussed on the preceding page for the 28½° missions, a preliminary summary has been made of the overall requirements for missions operating in the 57° and polar inclination orbits.

Mission equipment requirements for operations in a 57° inclination orbit consist primarily of externally mounted sensors for earth and atmospheric viewing, with a pressurized module for controls and data handling systems.

Mission equipment requirements for polar operations are similarly comprised of externally mounted sensors, with a large pressurized module for extensive development of sensors, controls and data handling systems.

Most of the missions specifying the 57° inclination would prefer, or could be satisfied by operation in a polar orbit, in which case these equipment and resource requirements could be combined.

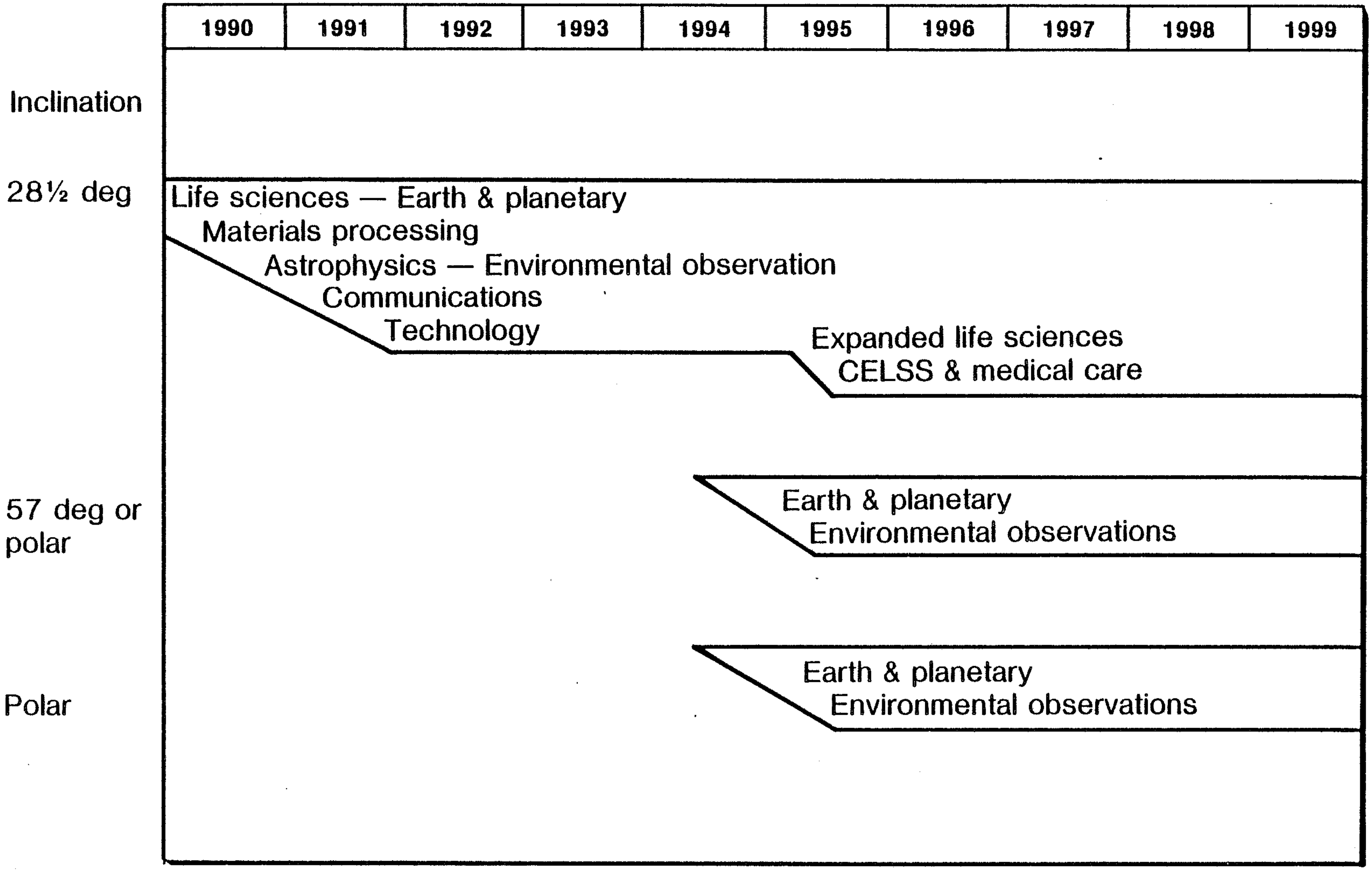
MAN-OPERATED FUNCTION
Summary — 57 & 90-deg Inclination

Requirement	57 Deg	90 Deg
Lab modules Equipment racks, cabinets, benches Sensor assemblies (typical) Sizes to 200 m Mass to 4,000 kg		
Orbit — Incl X alt Orientation	57 deg X 400-500 km Earth, celestial sensor point required	90 deg X 400-500 km Earth, celestial sensor pointing required
Operational	Logistics — 90 days On-orbit assembly of sensors	Logistics — 90 days
Crew-lab operations	~ 2 men Range of skills EVA required	3 to 4 men Range of skills EVA required
Power Avg Peak	~ 20 kW avg	~ 20 kW avg

The time-phased requirements for man-operated missions to a large degree are related to orbit inclination. The earliest requirements are missions that are satisfied with a 28.5° inclination LEO. These comprise research and development missions in low "g", and viewing from above the earth's atmosphere. Other missions such as Earth-Planetary and Environmental Observation missions are projected as starting at this inclination for early development, and being relocated on a higher (57°) inclination or polar orbit when such capability becomes available. The missions requiring a 57° inclination or the preferred polar orbit appear to focus on a start by the mid-90's. The polar orbit requirement, which would likely satisfy most or all 57° missions, is seen as also required no earlier than the mid-90's.

The choice to use the 57° or polar orbits lies with consideration of ETR vs WTR launch availability and the comparative payload delivery capability of the Shuttle from these two locations.

MAN-OPERATED FUNCTION
Time Phasing of Requirements



15112793-106

A major consideration in formulating concepts for accommodating the Space Station research and development labs, is the high potential for extending the use of Spacelab discipline laboratories for this purpose.

During subsequent phases of the study, the stated requirements for Space Station R&D capabilities will be examined versus the current or planned capability of each of the discipline labs, to recommend whether these labs in an uprated or modified configuration would appear to satisfy the Space Station requirements.

EVOLUTION — SPACELAB TO SPACE STATION

Spacelab

Discipline laboratories

- Space biomedical lab
- Space plasma lab
- Material sciences lab
- Shuttle telescopes & sensors

- Update
- Modify

Space station

Man-operated station labs

Man-tended free-flyers

Leo platform

15112793-151

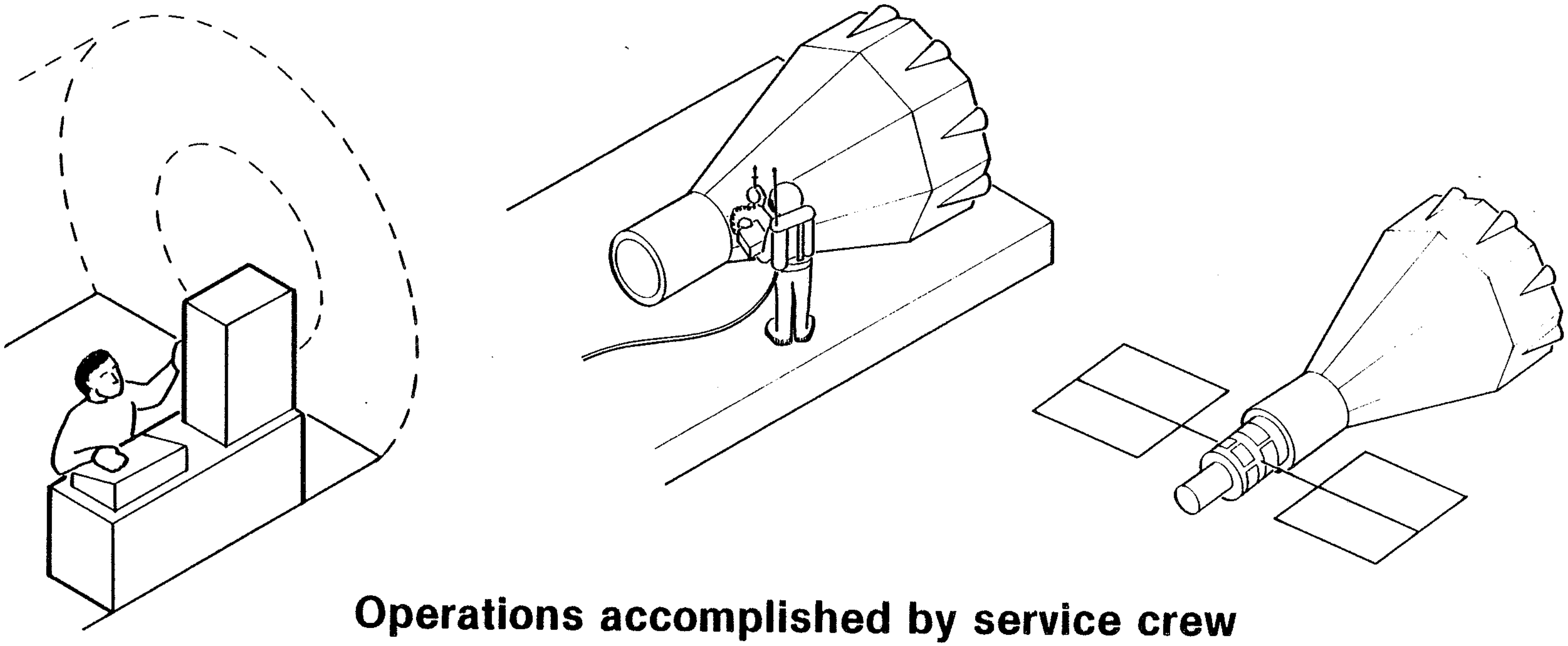
The free-flyers operating in the three required orbit inclinations include a wide span of physical sizes, which effects the servicing requirements and methods applicable to this group of spacecraft.

Free-flyers operating at 28½° inclination are primarily Astrophysics observatories. Many of these are very large observatories; several will require multiple shuttle flights and assembly on orbit. This large size also suggests the likelihood of servicing by visiting the observatory in-situ using TMS or shuttle, while smaller spacecraft could potentially be retrieved to the Space Station for servicing.

Free-flyers at the 57° and 90° polar inclinations are primarily Earth and Planetary, and Environmental Observation satellites of moderate size and therefore potentially serviceable from either the shuttle or a co-orbital station, use TMS or possibly OTV.

Service intervals and requirements are very preliminary in nature, and indicate possibility for accomplishing by shuttle or other visiting retrieval spacecraft; further definition of specific service requirements for each spacecraft is required.

MAN-TENDED FREE-FLYER FUNCTION



Operations accomplished by service crew

- Retrieval of free-flying satellites for update, servicing, consumables replenish, repairs, calibration
- Redeployment to operating orbit
- On-orbit support to satellite operations
  — Command-back-up or operational
  — Data reception/compression/retrans/distribution

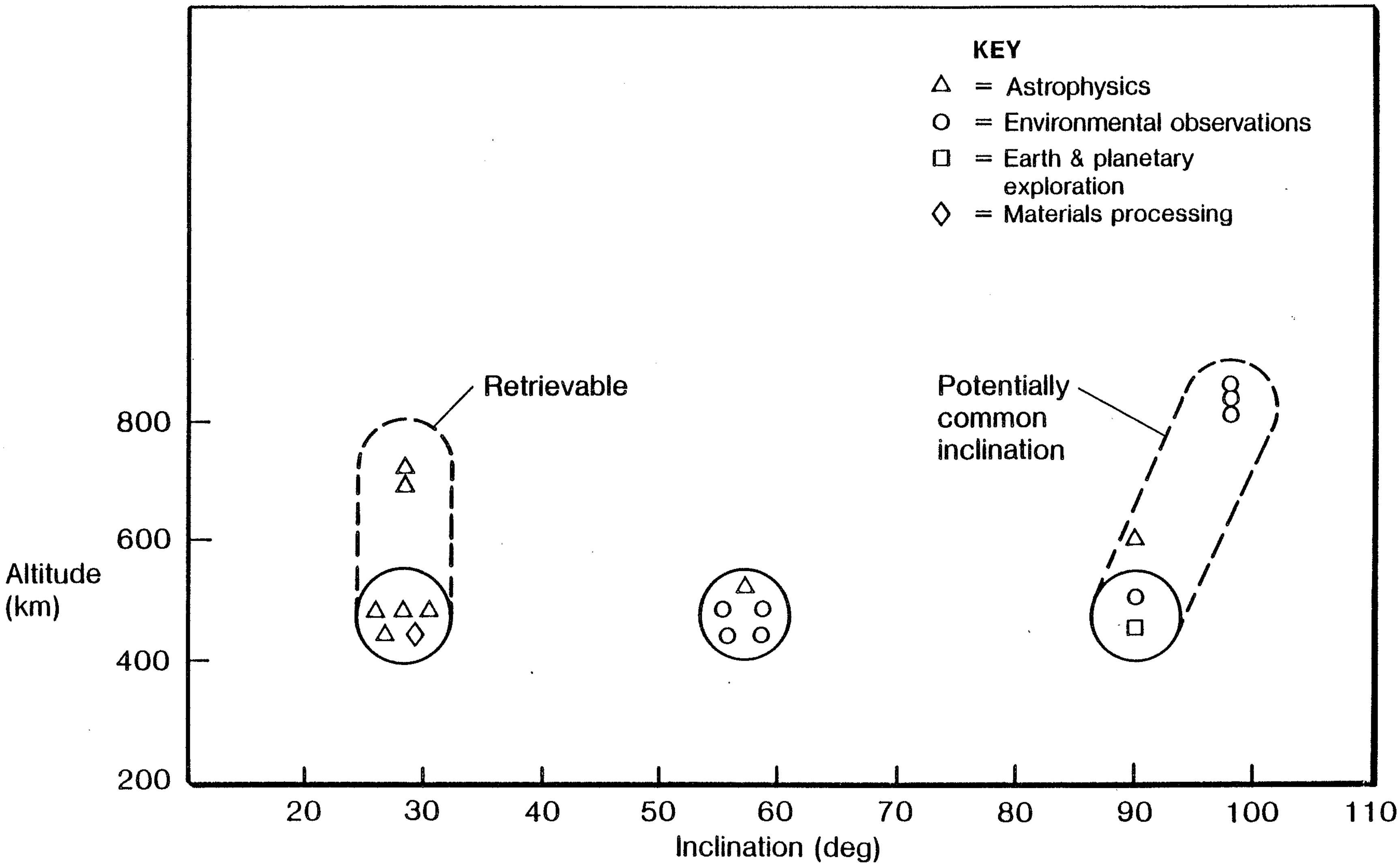
An analysis of Mission Requirements indicates a total of 18 free flyers needed in Low Earth Orbit (LEO) to satisfy the requirements of the mission. Grouped at an inclination of 28.5° and an altitude of 400-500 Km are one Materials Processing free flyer and 4 Astrophysics experiments. Two additional Astrophysics experiments are grouped at 28.5°, but at an altitude of 500-700 Km.

Five free flyers are grouped at an inclination of 57° at 400-500 Km. These include one Astrophysics experiment and 4 associated with Environmental Observations. Two Environmental Observation experiments are grouped at 90° inclination, 400 to 500 Km altitude. These highly inclined orbits provide for the required global coverage.

One Astrophysics experiment is scheduled for a 90° inclination at 500 to 700 Km, and 3 Environment Observations experiments at an inclination of 98° and an altitude of 800 Km. Of these 3, two are the same (WINDSAT) but orbiting at a fixed spacing from each other.

This tentative grouping permits Space Station architecture planning to support free flyer missions using the minimum number of station elements or support items.

LEO FREE-FLYERS



15112793-84

Low earth orbit free-flyer missions generally fall into the same groupings of orbit inclination as the man-operated missions, for much the same reasons:

- 28.5° - inclination for conduct of automated low "g" processes or viewing from above the earth's atmosphere.

- 57° - inclination for adequate coverage of the earth's surface or considerations of Van Allen belt latitudes for Plasma and high energy missions.

- Polar orbits for global coverage of the earth's surface or atmosphere.

The man-tended free-flying function includes those free-flyers which can be serviced from the Space Station or the Shuttle Orbiter , facilitated by TMS as required. The service intervals shown are early judgments; actual times must consider optimum life of stored consumables, likelihood of a change in sensors, unscheduled repairs, and service methods and costs.

LEO FREE-FLYER MISSIONS

Altitude	Inclination			Mission
	28.5 deg	57 deg	90 deg	
400-500 km				**Astrophysics**
	X			• Relativistic gravitational exp
	X			• Gravitational radiation search
	X			• IR interferometer
	X			• Thinned aperture telescope
		X		• Solar observatory
	X			**Material processing**
				Environmental observations
		X		• Solar terrestrial observatory
		X		• Meteorology instruments group
		X		• Space plasma physics
		X		• Upper atmosphere research P/L
			X	• Ocean color
			X	• Land features
500-700 km				**Astrophysics**
	X			• Sub-millimeter telescope
	X			• IR telescope
			X	• Gravity probe-B

15112793-154

Free flyer servicing operations may be performed at the Space Station or in the free flyer orbit by the use of TMS/RMS or OTV/TMS. In either case, the TMS or Space Station must be able to command the free flyer to deactivate/activate systems and for spin stabilized satellites, to command them to despin.

During the despin period and subsequent servicing, the free flyer arrays must be protected from heat and cold.

The free flyer and TMS/RMS must both be designed for automatic servicing to include: checkout/diagnostics, consumable resupply, exchange/add sensor, and planned maintenance.

Unplanned maintenance or planned maintenance on free flyers not designed for automatic servicing will be performed at the Space Station by use of RMS or EVA.

FREE-FLYER SERVICING OPERATIONS

- Free-flyer command & control to prepare for servicing
- Free-flyer checkout/diagnostics
- Resupply consumables
- Exchange/add sensors
- Planned/unplanned maintenance
- Protect from environment during servicing

Servicing of free flyers co-orbital with the Space Station may be performed either in-situ by TMS or at the Space Station by TMS/RMS based upon the following factors:

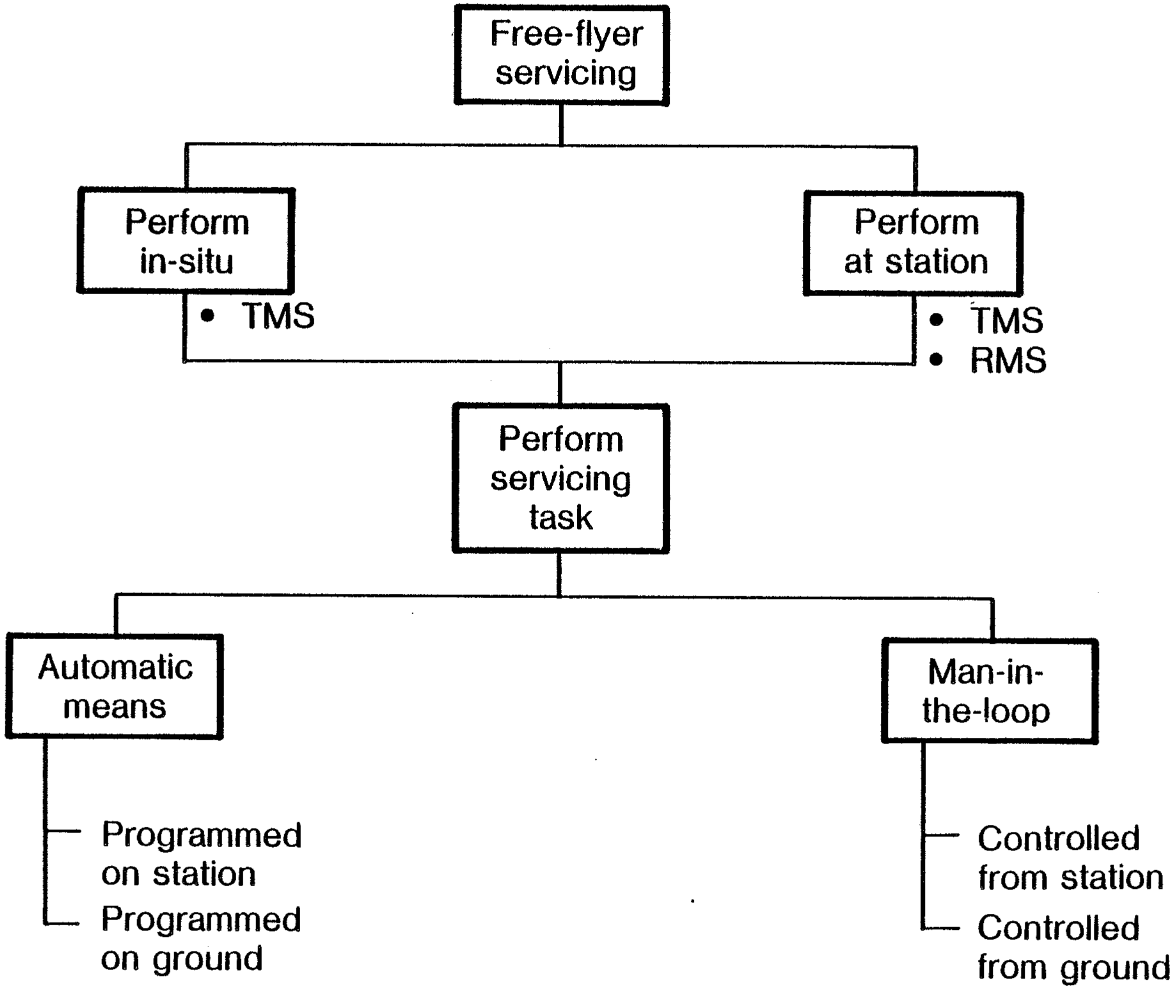
- Degree of automatic servicing free flyer is designed for
- Economic trade-off-time/cost for preparation
- Time available for servicing
- Number of times servicing is required
- Planned versus unplanned maintenance

The servicing task may be performed by automatic means or man-in-the-loop dependent upon the degree of automatic servicing designed into the free flyer.

If servicing is to be performed by automatic means, the servicing task may be programmed on the Space Station or the ground based on cost, crew loading, computer capability, checkout simulation, controls and displays, and overall timelines.

If servicing is to be performed with the man-in-the-loop, the servicing task may be controlled from the Space Station or the ground dependent upon relative orbits, communication links, crew loading, station autonomy and controls/displays.

FREE-FLYER SERVICING OPTIONS
Free-flyer Co-orbital With Station



15112793-76

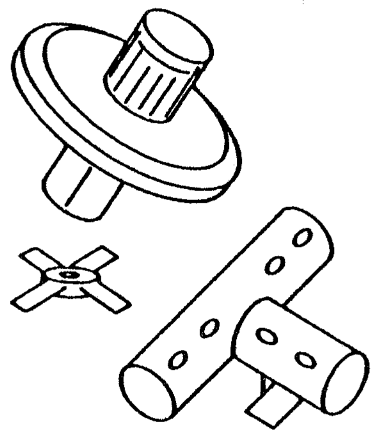
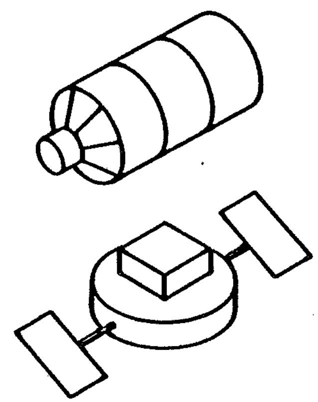
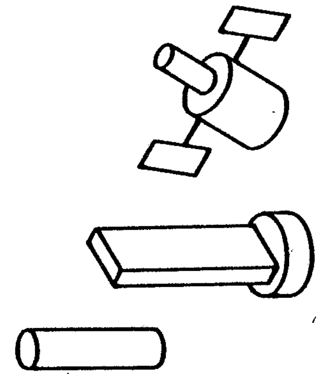
Missions accomplished by spacecraft operating as free-flyers in LEO, and which require or would significantly benefit from manned service on-orbit, are included in the man-tended free-flyer function.

These servicing operations are aimed at extending the useful life of the spacecraft, while minimizing the on-board provisions for consumables storage, provisions for redundant elements, or automatic replacement of sensors.

The free-flyers operate in orbits which have altitude and inclination limits which make some of them accessible for servicing from a co-orbital manned Space Station, while the balance could be serviced from the Space Shuttle Orbiter.

Servicing from a co-orbital Space Station offers the greatest potential for cost savings since shuttle service launch costs are minimized. This method also has potential for the most performance benefits, since the servicing operation is not constrained to be completed within the limited on-orbit stay time of the Orbiter.

MAN-TENDED FREE-FLYER FUNCTION
Summary — LEO — 400-700 km

Requirement	28½ deg	57 deg	90 deg
Typical spacecraft			
Avg no. in operation Size Typical mass	3-5 To 100 m diam 10,000 kg to 65,000 kg	2-4 To 32 m diam To 12,000 kg	2-4 To 15 m To 3,000 kg
Service interval Access means	2-3 years Visit — TMS or OTV/TMS — Option-Shuttle	2-3 years Visit — shuttle or OTV/TMS	2-3 years Visit — shuttle
Crew — per service Control of FF/TMS EVA	1 to 2 men 2-5 days Required	1 to 2 men 2-5 days required	1 to 2 men 2-5 days required
Power-service	<1 kW avg	<1 kW	<1 kW

15112793-153

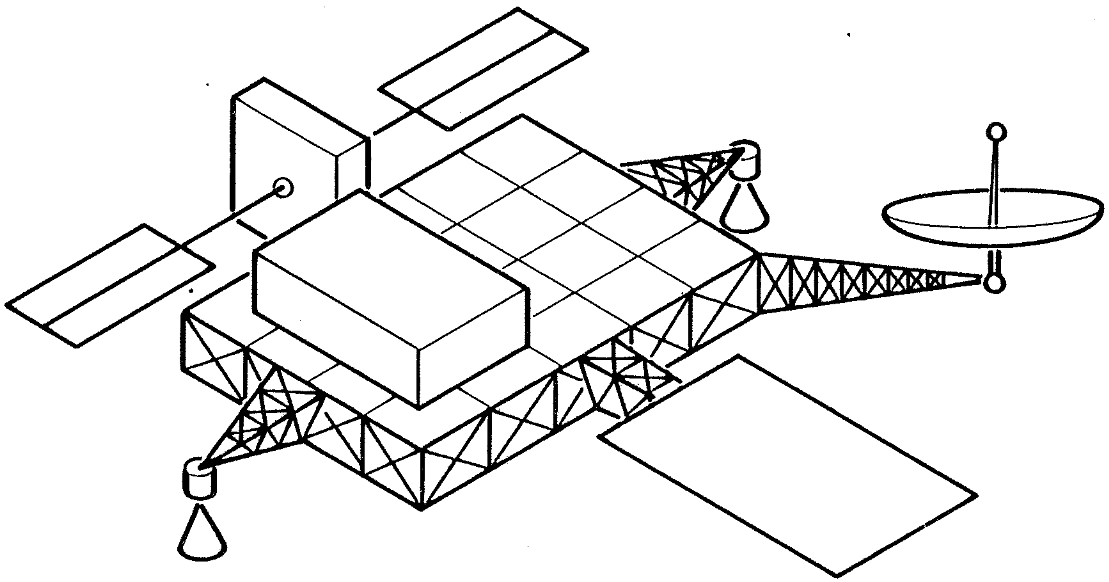
Many of the free-flyers operating in LEO have similar orbital altitude and inclination requirements, which offers the potential for grouping these spacecraft on a single platform. Such sharing can be in parallel timewise, or could be shared sequentially by time-separated spacecraft.

Grouping of spacecraft on a single platform permits sharing of platform services such as stabilization/pointing, electrical power, data and communications, thereby reducing spacecraft cost and weight, with resultant reduction in launch costs for the spacecraft.

Where two or more spacecraft are mounted on the platform at the same time, servicing missions can be combined and the cost shared for further reduction in operating costs.

Platforms in 57° and polar inclination orbits also provide the nucleus or starting point for later growth to a manned Space Station.

LEO PLATFORM FUNCTION



Services provided by platform

- Mounting provisions for sensors
- Orientation & pointing
- Electrical power
- Data collection, handling & distribution
- Docking provisions for Orbiter servicing (Initial)
- Growth to servicing from co-orbital station (Later)

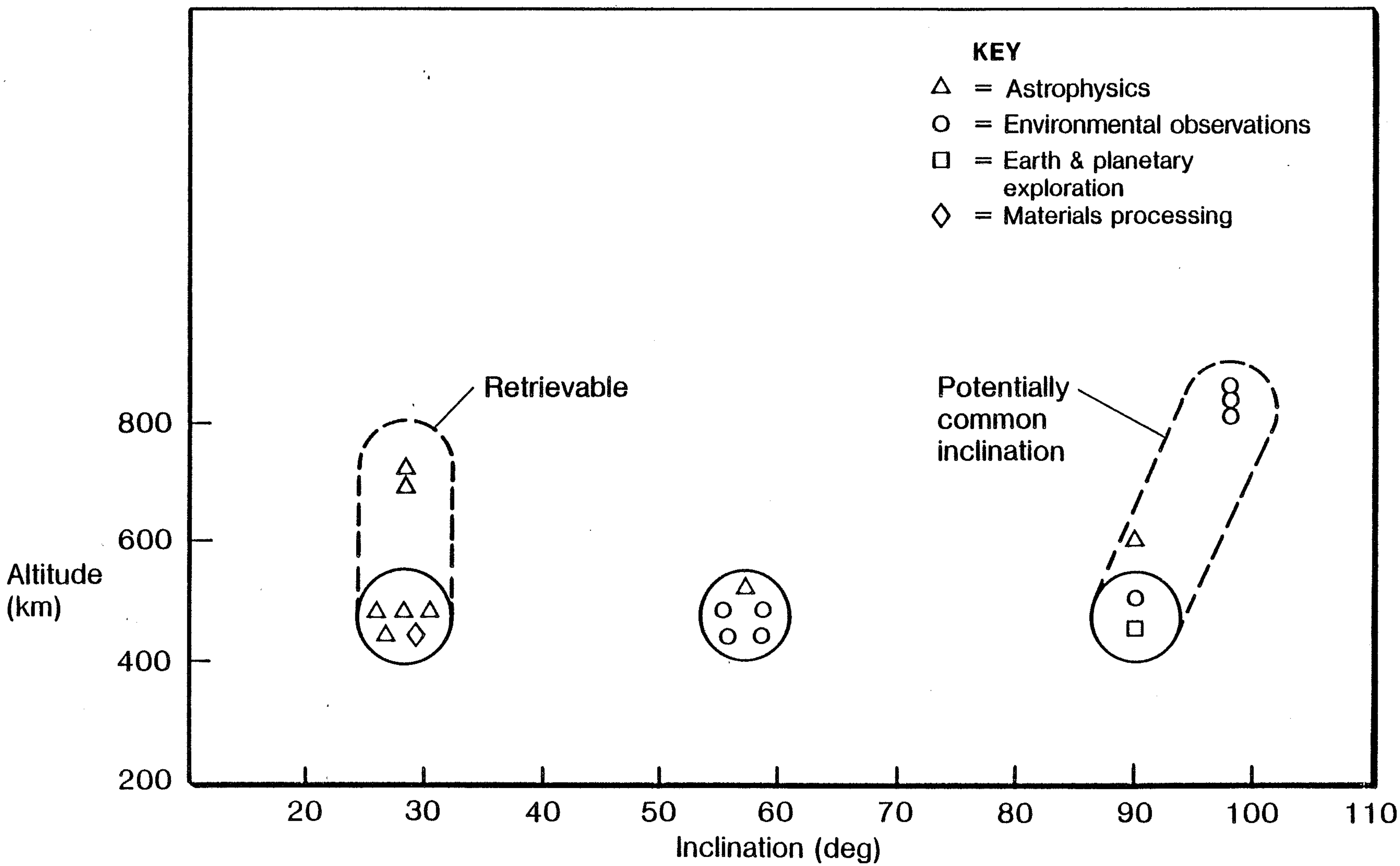
15112793-33

The coincidence of orbit requirements for a number of free-flyers makes them candidates as LEO platform payloads. For example, of the five free-flyers at 28.5° and 400-500 Km, four are Astrophysics missions. In addition, two other Astrophysics missions require 28.5° and 500-700 Km. These are obvious LEO platform candidates, possibly for a single platform. The Materials Processing Mission for 28.5°, 400-500 Km is probably not a candidate for the same platform because of conflicting mission requirements.

There is a similar group of Environmental Observation Missions at 57° and 400-500 Km which are candidates for another LEO platform.

Two other Environmental Observation Missions occur at 90° and 500-700 Km along with three at 90° and 800 Km. Two of the latter are WINDSATS requiring a constant spacing and are therefore not candidates for the same platform. However, one WINDSAT plus the other 98°/800 Km and the two 90°/500-700 Km missions are candidates for a LEO platform at 98° inclination. It is recognized that the 98° orbit is needed to accomplish mission objectives but the 90° Environmental Observation Missions are probably amenable to 98° because they are interested primarily in global coverage.

LEO FREE-FLYERS



15112793-84

Servicing of free flyers not co-orbital with the Space Station may be performed either in-situ by OTV/TMS by the Shuttle with TMS, or by waiting for orbital conjunction with the Space Station and using OTV/TMS. The option selected will be based on the following factors:

- Orbital parameters/communication links
- Degree of automatic servicing free flyer is designed for
- Economic trade-off-time/cost for preparation
- Time available for servicing
- Number of times servicing is required
- Planned versus unplanned maintenance

The servicing task may be performed by automatic means or man-in-the-loop dependent upon the degree of automatic servicing designed into the free flyer.

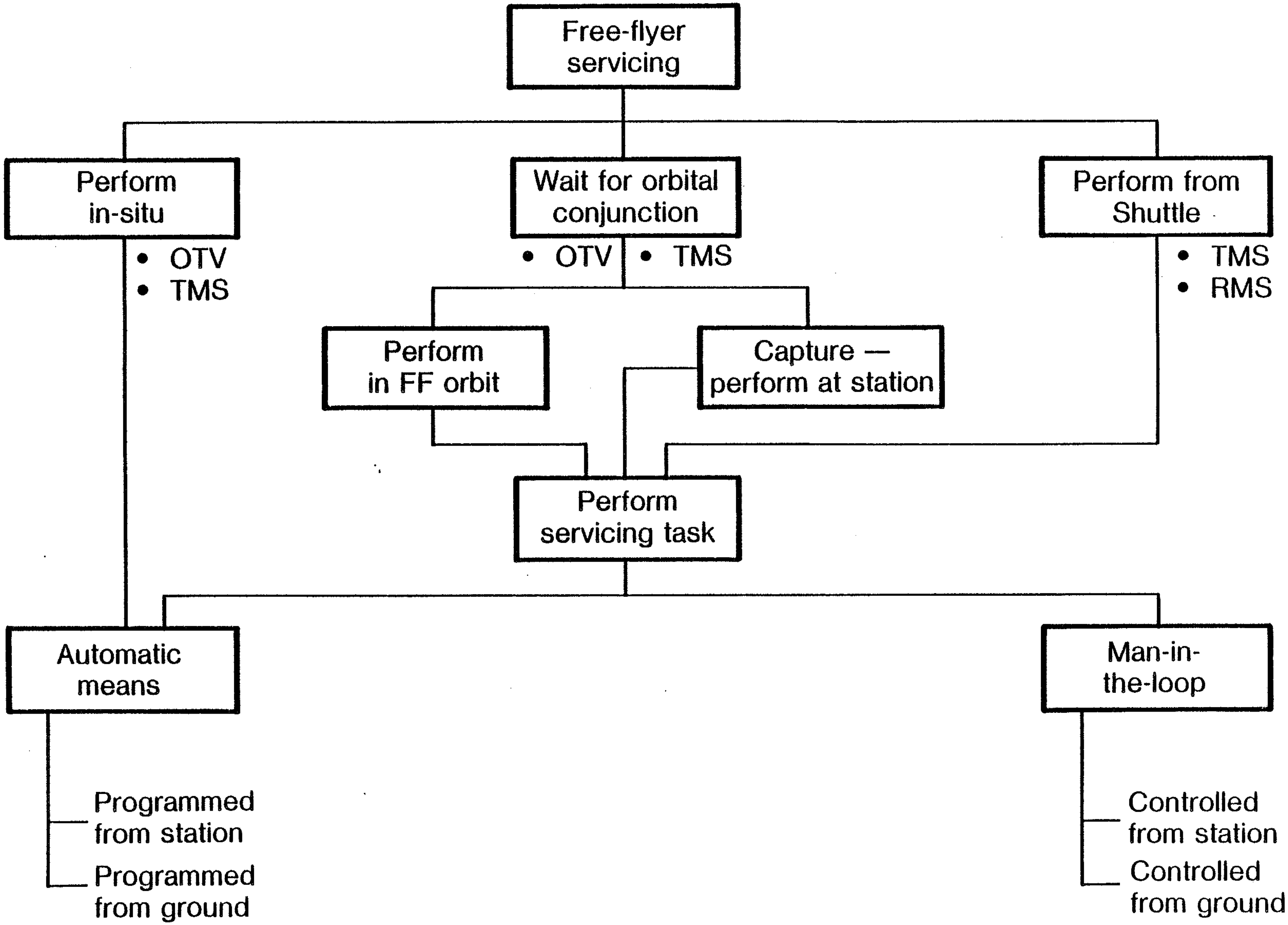
If servicing is to be performed by automatic means, the servicing task may be programmed on the Space Station or the ground based on cost, crew loading, computer capability, checkout simulation, controls and displays, and overall timelines.

If servicing is to be performed with the man-in-the-loop, the servicing task may be controlled from the Space Station or the ground dependent upon relative orbits, communication links, crew loading, station autonomy and controls/displays.

FREE-FLYER SERVICING OPTIONS

Free-flyer Not Co-orbital With Station

GENERAL DYNAMICS
Convair Division



15112793-77

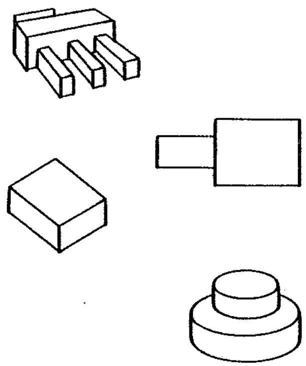
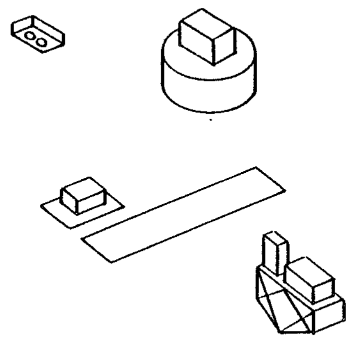
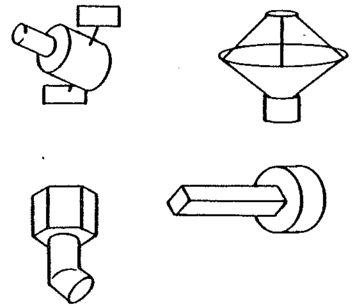
A review of the spacecraft operating in the free-flying mode in LEO, indicates the potential for grouping these onto platforms in all three inclinations. This is especially true for the smaller spacecraft that are currently projected to be in each orbit.

The current allocation of requirements indicates that only one or two spacecraft per orbit inclination would be operating at any point in time. However, existence of a platform would be of benefit for attaching the spacecraft in a time-sequenced manner. Also the capability to economically extend the useful life of spacecraft by shared service visits could result in an increase in the actual number in operation.

Of particular value would be the platform at polar orbit where the weight savings made possible by platform sharing and servicing helps to compensate for the lesser payload capability of the Shuttle at this inclination.

GENERAL DYNAMICS
Convair Division

LEO PLATFORM FUNCTION
Summary

Requirement	28½ deg	57 deg	Polar
Candidate missions • Astrophysics • Environmental observations • Earth/planetary	Astro 	EO, Ep 	Astr. EO E/P 
Size range Mass range	2-6 m 1,000-3,000 kg	1-50 m 100-2,500 kg	to 20 mℓ 1,000-4,000 kg
Avg no. in operation	1-2	1-2	1-2
Orbit — incl & alt Orientation	28½ deg × 400-500 km Earth & celestial	57 deg × 400-500 km Earth & celestial	90/98 deg × 400-700 km Earth & celestial
Operating resources Power — avg Data — gen rate	 4 to 12 kW <1 mBps	 10 to 20 kW <1 mBps	 4 to 12 kW 150 to 300 mBps TV during servicing
Servicing requirements Service interval Crew — time Power	 2 years 2 men — to 5 days <1 kW	 2 years 2 men — to 5 days <1 kW	 2 years 2 men — 5 days <1 kW

15112793-71

The basic spacecraft support requirements of the OTV Basing Function derive from the on-orbit spacecraft preparation and checkout for launch aboard the OTV to HEO, GEO and Planetary missions.

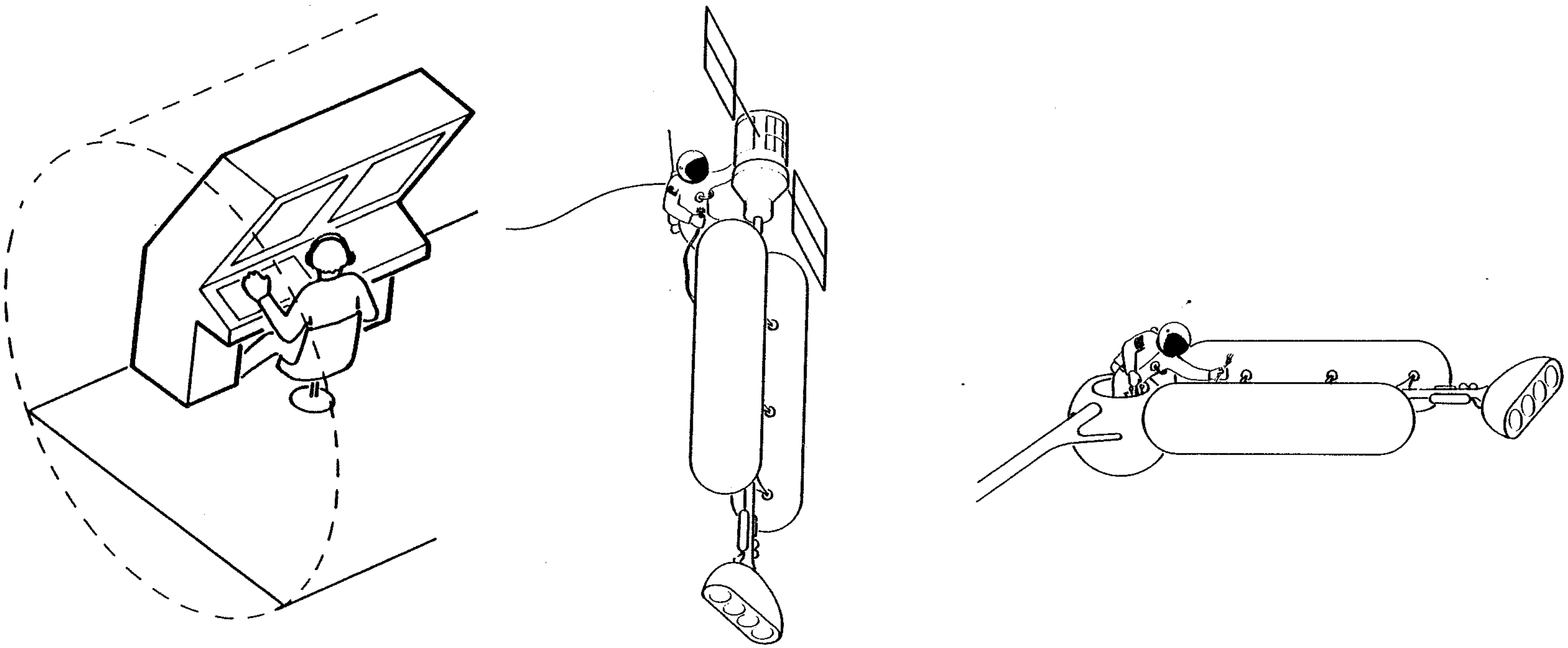
In the initial years these requirements are seen as limited to the checkout and servicing of the spacecraft prior to commitment to their operating orbit. A key feature of the checkout is the RF link to ground POCC for closed loop checkout of spacecraft command and data nets, requiring high data rates in some cases.

Resource requirements for these operations are dependent on spacecraft design to accommodate the servicing, and launch rates, which in early years are projected as limited.

During later years a higher rate of launches on OTV is forecasted, as well as on-orbit assembly of very large spacecraft structures and antennae.

The requirement for EVA is anticipated to permit assembly of very large antennae, and to perform or assist in the deployment of solar panels and other large structures. Further growth in OTV basing function requirements is foreseen with the beginning of in-situ servicing of GEO spacecraft, or by retrieval and return to LEO.

OTV BASING FUNCTION



Operations accomplished by station crews

- Spacecraft transfer from orbiter, assembly & mating to OTV
- Spacecraft checkout, RF to ground, repairs & adjustments
- Launch of OTV/spacecraft to HEO, GEO & planetary orbits
- Retrieval & servicing of spacecraft from HEO & GEO orbits
- Launch & control of OTV/TMS servicing of spacecraft at GEO
- OTV maintenance, fueling & flight preparations, launch & boost command, flight monitor/control & retrieval

15112793-31

Missions included in the OTV basing function are predominantly Geosynchronous satellites and interplanetary probes. Also included are spacecraft to be delivered to high inclination/high altitude earth orbit. The great majority of the satellites require propulsive energy of the level projected for the OTV. Some, however, may be deliverable by smaller stages such as the PAMs or the TMS.

The use of a reusable propulsive stage operating from LEO, offers considerable payoff in both performance and economic benefits. The Orbiter delivers the spacecraft to an OTV operations base in LEO, where they are mated to an OTV or required stage, and transferred to their operating orbit.

In early years, GEO spacecraft would be delivered by an upper-stage, i.e., IUS or Centaur, operating from the Shuttle Orbiter, while for low energy cases they may use integral spacecraft propulsion or a TMS.

During later year OTV basing operations, the satellites could be grouped for launch by the Orbiter, and subsequently by the OTV, where weights allow. A further growth is possible by grouping the spacecraft on a platform similar to the LEO case for sharing of platform services, thus reducing spacecraft construction, launch and servicing costs.

A growth is foreseen where these satellites could be retrieved from their operating orbits by the OTV, and returned to the OTV base for servicing or repair, or repaired in-situ by an OTV/TMS vehicle.

TYPICAL MISSIONS — OTV BASING FUNCTION

Discipline	Title	Operation
Earth & planetary	Mars orbiter	Activate/deploy systems Insert into transfer orbit Retrieve sample return capsule
	Near-Earth asteroid rendezvous	Activate/deploy systems Insert into orbit
	Comet sample return	Activate/deploy systems Insert into orbit Retrieve sample return capsule
Communications	Small satellites	Activate/checkout systems Transfer to GEO
	Large satellites	Assemble/deploy antennas Activate/checkout systems Transfer to GEO
National security	Geostationary satellite	Activate/checkout systems Transfer to GEO
Astrophysics	Interferometer	Activate, deploy/assemble systems Transfer to HEO
Envir observation	Wind scatterometer	Activate/deploy systems Transfer to HEO

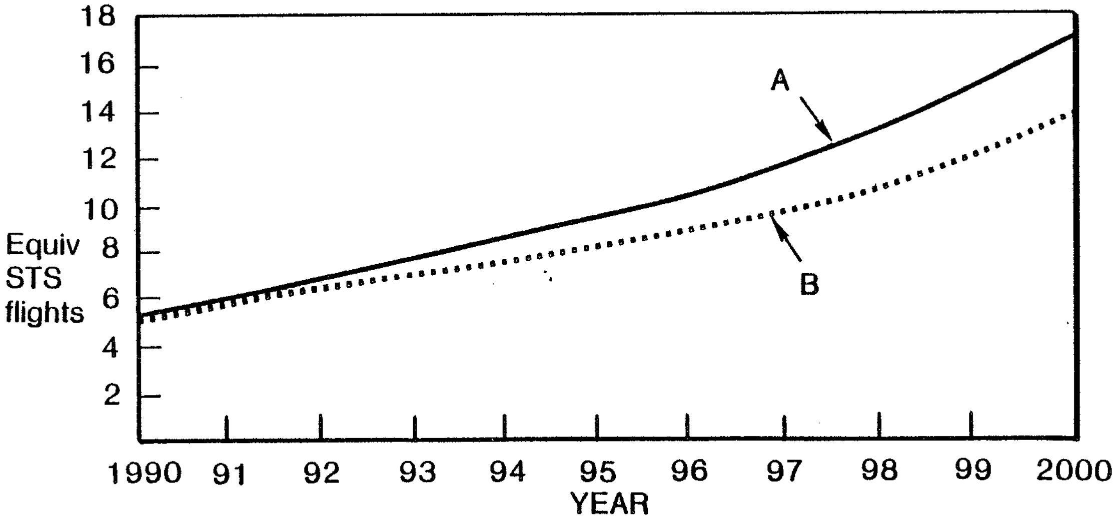
15112793-91

A communications traffic model for the years 1990 through 2000 was constructed by using an average of both NASA and industry sources. (MSFC, JSC, Boeing, Battelle, R.I., and Western Union). This survey indicates that communication satellite traffic will reach a level of about 17+ shuttle equivalent flights per year by the year 2000. To test the validity of this prediction, a second model was constructed based on the anticipated need for communications transponders. An average growth rate of 15% per year was used, translating into a factor of 25% to 30% satellite use for long distance traffic by the year 2000. The model incorporated a decrease in transponder weight over the time period. The result (curve B) correlates closely with the industry prediction (curve A). The curve, of course, can be modified by an assumed growth rate of greater than 15% per year. In addition, there will be space system launches of direct broadcast satellite and multi-use communication platforms that were not included in curve B. By the year 2000, the average size of communication satellites is expected to increase, with a corresponding increase in the number of transponders per satellite.

The DoD traffic model was taken from the MSFC Mission Model, Rev. 6 (curve C). It is assumed that all traffic to GEO is launched from ETR. It is also assumed that almost all of the DoD satellites launched from ETR are destined for deployment in GEO.

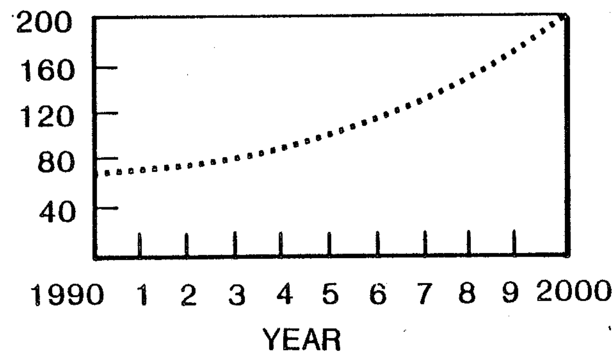
OTV TRAFFIC MODEL

Domestic & international commun satellites



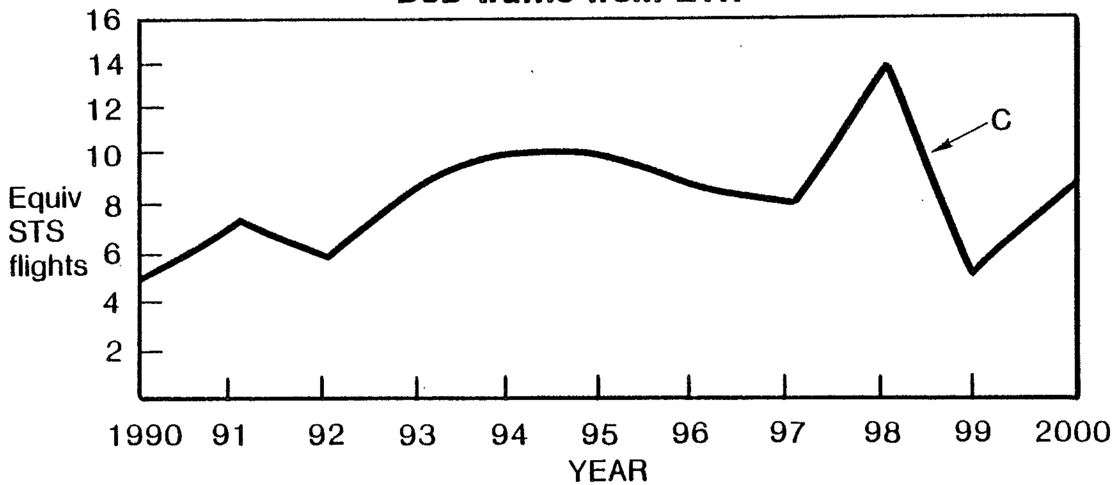
A — Average of industry projections

B — Equiv flights based on 15% increase per year transponder growth & technology advances



Projected no. of transponders per satellites

DoD traffic from ETR



C — Rev 6; MSFC OTV mission model, Sept 82

15112793-74

The availability of the Space Station will enhance exploratory missions to the planets and other solar system bodies in the 1990's time frame. The main contribution will come in the area of preparation and launch of the spacecraft to escape trajectory. For specific missions the station will also be involved in retrieval of a returning spacecraft carrying planet or comet samples.

Launching of a spacecraft for planetary rendezvous must occur within a known window, of a few days duration, for a given mission opportunity. Without the Space Station this factor would require scheduling of shuttle flights to carry the spacecraft to LEO during launch windows. The availability of a Space Station permits the spacecraft to board a convenient shuttle flight before the launch window, without disturbing the shuttle schedule established for other users. Upon rendezvous with the Space Station, the crew will transfer the payload from shuttle to station, mate it to the OTV, deploy solar panels and antenna, and check out functioning of spacecraft systems. The spacecraft propulsion system, which accomplishes trajectory corrections en route and orbital insertion at the destination, will be fueled from the Space Station. The spacecraft will then be launched into escape trajectory at the optimum time.

The comet HMP and Mars surface sample return missions will return modules containing the samples to earth. These will enter low earth orbit in the proximity of the Space Station with retrieval by TMS or OTV. The sample will then be transferred to an appropriate laboratory on the station for analysis.

OTV BASE
Planetary Missions Support

Launch support candidates

- Missions
  - Two per year average traffic
- Servicing: fuel spacecraft, checkout

Payload return data capsule retrieval

- Missions
  - Comet HMP sample return, 1998, 1000 kg
  - Mars surface sample return, 1999, 2800 kg
- Rendezvous in LEO
- Extract/quarantine sample
- Test/analysis of sample

The OTV base must provide the following support functions for a space based OTV:

- Docking - provide automatic rendezvous and low g docking
- Checkout/diagnostics - checkout OTV and OTV/payload integration
- Mission command and control - provide automatic control with crew access to all functions
- Propellant storage loading and unloading - provide safe, low loss, automatic propellant storage and handling system
- Payload mating and integration - provide RMS for mating and automatic checkout facilities for OTV/payload integration
- Maintenance actions - provide automatic traversing work station operator for avionic package removal and replacement, engine removal and replacement, and tank repairs
- Spares storage - provide storage modules for spares and parts awaiting refurbishment

The OTV base must provide the following prelaunch support functions for HEO payloads:

- Handling - provide a remote manipulating system (RMS) for assembly, servicing, and mating with OTV
- Activation and checkout - provide automatic command and control system for activation, checkout, and launch/mission control
- Servicing and maintenance - provide automatic traversing remote operator for servicing and scheduled/unscheduled maintenance where this is determined to be an economic approach

OTV BASE OPERATIONS

OTV support functions

- Docking
- Checkout/diagnostics
- Mission command & control
- Propellant storage, loading & unloading
- Payload mating & integration
- Maintenance actions
  - — Avionic package removal & replacement
  - — Engine removal & replacement
  - — Tank repairs
- Spares storage

Support functions for HEO payloads

- Handling
- Activation & checkout
- Unscheduled maintenance — e.g. avionic package R&R
- Servicing (candidate)

Resources for the operations to be conducted as part of the OTV basing function to provide spacecraft economic and performance benefits include handling, servicing and checkout of the spacecraft, prior to launch on the OTV.

During subsequent phases of the study, these areas will be examined for requirements versus potential benefits to the spacecraft programs to define and quantify the resources required to accomplish these operations.

OTV SPACECRAFT OPERATIONS — RESOURCE REQUIREMENTS

- Spacecraft handling
  - Transfer & holding facilities
  - Assembly provisions
  - Crew & controls
  - Power
- Spacecraft servicing
  - Antenna & panel extension provisions
  - Consumables storage & loading equipment
  - Spares storage
  - Repair facility
  - Crew — including EVA provisions
  - Power
- Spacecraft checkout
  - Interface connections — control, data
  - Data processing
  - RF link to ground/POCC
  - Crew & controls
  - Power

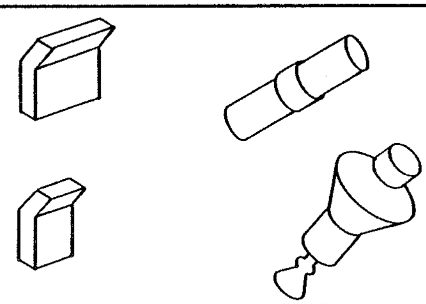
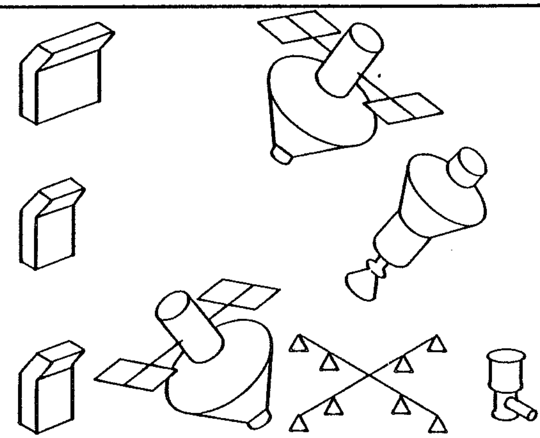
Missions which include spacecraft for delivery from the Shuttle in LEO to a HEO/GEO or planetary mission orbit, are included in the OTV basing function.

While most of the spacecraft will require an OTV class vehicle for delivery to operating orbit, some may be deliverable by a much smaller class, such as TMS.

A major economic benefit is projected by use of a reusable OTV operating from a fueling and launch base in LEO. Only the spacecraft is delivered aboard the Shuttle to LEO. The OTV and propellant are based at LEO with several options awaiting for economical delivery of propellants to LEO. This basing significantly reduces spacecraft launch costs to LEO. Re-use of the OTV further reduces the cost of delivery of the spacecraft to its operating orbit.

Added benefits of this OTV operation are provided by the capability to conduct preparations and checkout of the spacecraft at LEO, prior to commitment to GEO, HEO or planetary missions.

OTV BASING FUNCTION
28½-deg Inclination — LEO

Resource	Mission Requirements	
	Initial Years	**Final Years**
Missions • Communications • Planetary exploration • Environmental observation • National Security Size to 33m dia 6,000 kg		
Launch Frequency	**3 to 4 per year**	**20 to 30 per year**
Operations	Mate to OTV Deploy antenna & panels Checkout — RF link to ground Fuel spacecraft, launch	Assemble large antenna, spacecraft Checkout RF link to ground Mate to OTV Fuel spacecraft, launch, Retrieve from GEO, refurb
Crew requirements	2 men ~ 1 day communications ~ 5 days — planetary EVA required — service	2 men ~ 1 day — communications ~ 5 days — planetary ~ 40 days — env observation Variable for retrieval, refurb EVA required — assembly, service
Power — avg	<1 kW	<1 kW
Data — gen rate	<1 mBps	1 to 30 mBps

15112793-83

The time-phasing of the OTV basing function requirements is dependent on several major considerations, including transition from current or planned upper stages - PAM, IUS and Centaur - to the re-usable OTV. A parallel consideration is the design of spacecraft for compatibility with the OTV. Another major consideration is the projected increase in both launch rate and spacecraft size.

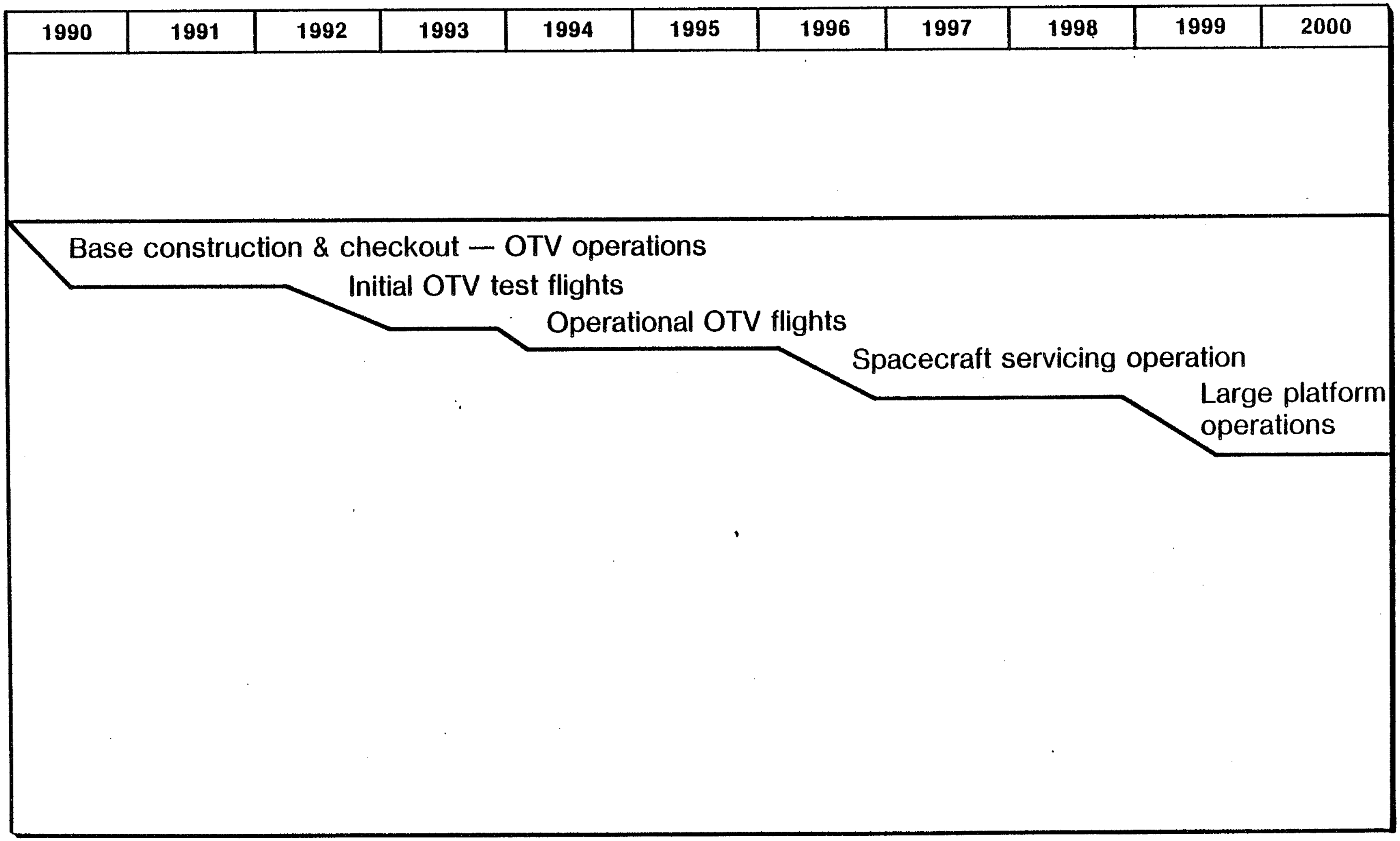
For the case of the transition to re-usable OTV taking place in the early part of the 1990's the following time-phasing of requirements applies:

- Spacecraft servicing and checkout resources are required starting with the initial spacecraft delivery using the operational OTV. Resources to support servicing of spacecraft at GEO - or by return to LEO - are required by the following two or three years.

- Final years of the decade require the capability to assemble and launch very large platforms containing either large antennae, or multiple spacecraft.

- OTV base construction, checkout and test flights need to be completed in time to support the transition to the operational space-based OTV.

OTV BASING FUNCTION
Time Phasing of Requirements



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A preliminary review of the GEO mission spacecraft, together with consideration of the projected GEO population problems, indicates that grouping of payloads onto platforms is both necessary and economically beneficial.

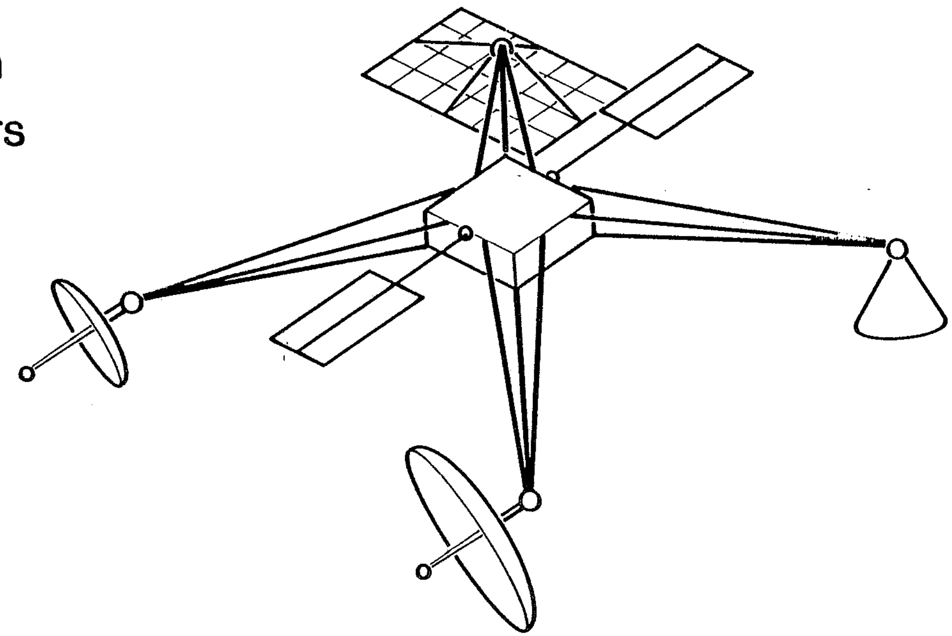
One mission plan currently projects the launch of an experimental GEO platform in the 1980's, followed by an operational platform in the early 1990's, and a very large platform which will potentially require multiple OTV loads before the close of the decade.

At this stage in the analysis of mission requirements, no further requirements for the GEO Platform have been defined. This will require further study during the second phase of the study. Of primary concern in this grouping is the need for RF compatibility between emissions/receptions of the grouped spacecraft.

GEO PLATFORM FUNCTION

Services provided by platform

- Mounting provisions for sensors
- Orientation & pointing
- Electrical power
- Data handling
- Docking for service by OTV



Candidate spacecraft

- Operational GEO platform
- Groupings of small, RF-compatible communications satellites
- Groupings of large antennae & sensors — communications, envir observation spacecraft

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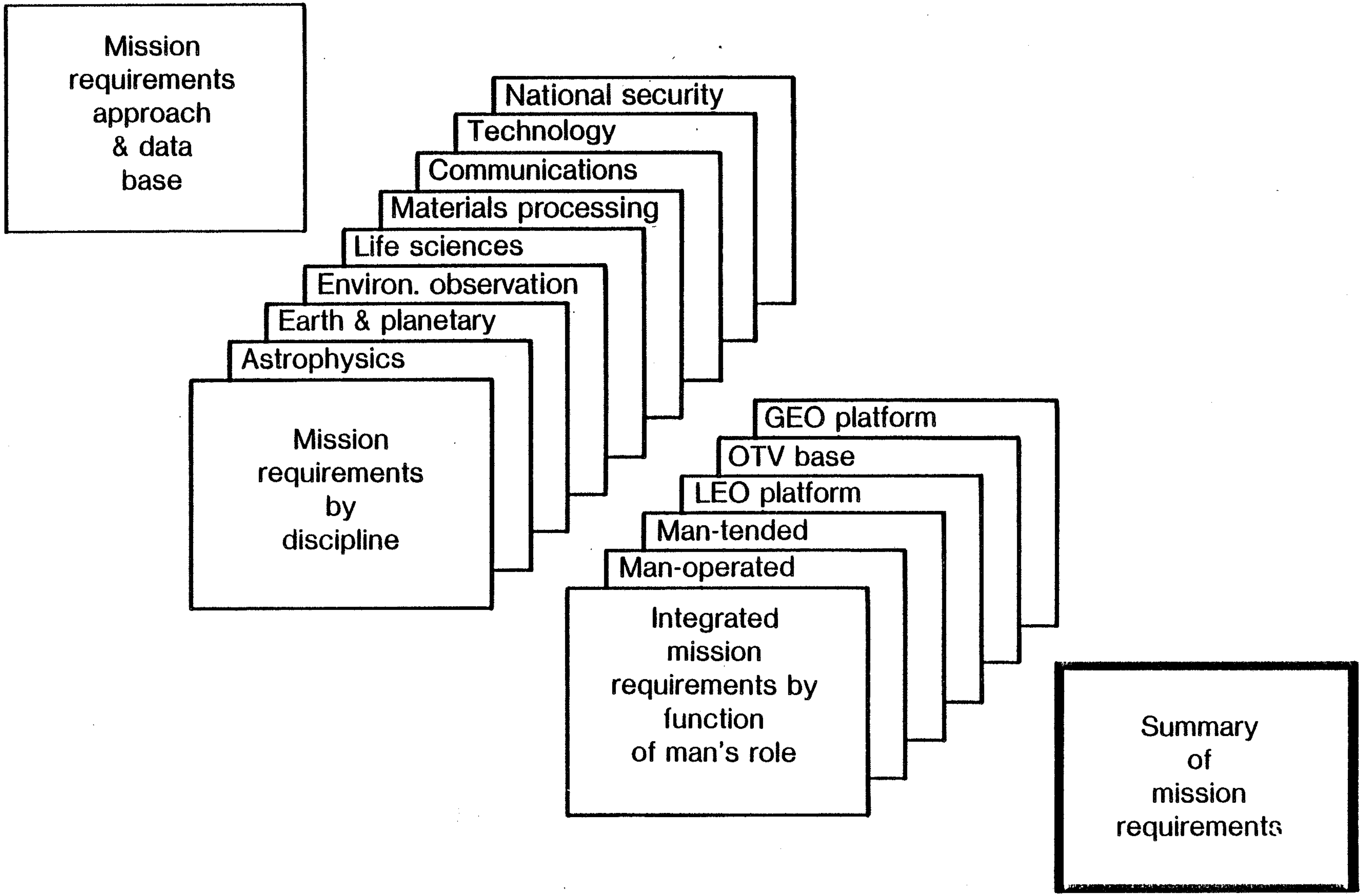
Presented in this section is a summary of the principal results and conclusions of the mission requirements task to date.


Mission requirements approach & data base
National security
Technology
Communications
Materials processing
Life sciences
Environ. observation
Earth & planetary
Astrophysics
Mission requirements by discipline
GEO platform
OTV base
LEO platform
Man-tended
Man-operated
Integrated mission requirements by function of man's role
Summary of mission requirements

15112793-56

The accommodations necessary to meet mission requirements for the initial phase of the Space Station includes a basic capability in LEO 28.5° inclination to house mission equipment, and provide resources - crew habitat, power, and station support systems for the early year missions.

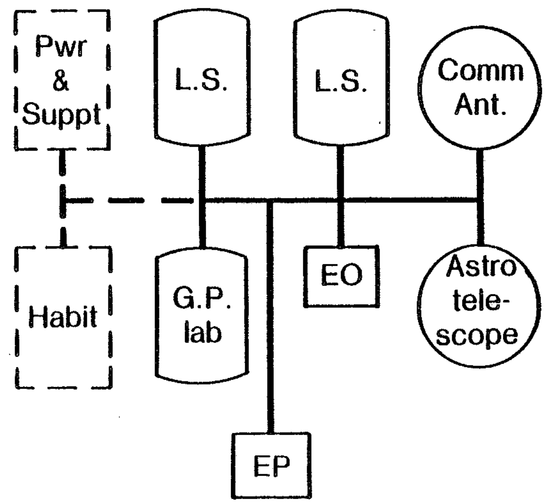
Summation of free-flyers operating in a wide range of orbits shows a need to accommodate servicing capabilities and resources for about 4 free-flyers. These free-flyers will be added to those existing in orbit in 1990, which if so designed, could also be accommodated by Space Station servicing, e.g., Leasecraft.

An OTV basing capability is required to coincide with OTV operational capability, to service and launch approximately 2 to 3 DoD satellites per year plus 1 to 2 communication satellites and planetary missions.

SUMMARY OF MISSIONS — INITIAL REQUIREMENTS (1990/1991)

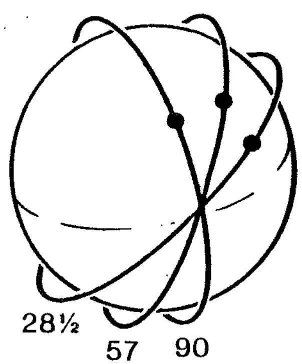
Man-operated 28½°
400-500 km

2 modules — life sciences
1 general purpose module
1 communications antenna
1 astro telescope
1 env obs pallet — 4m × 10m
1 earth plan pallet — 4m × 6m
4 to 6 P/L crew
~20 kw avg
(DoD-R&D can be accommodated)



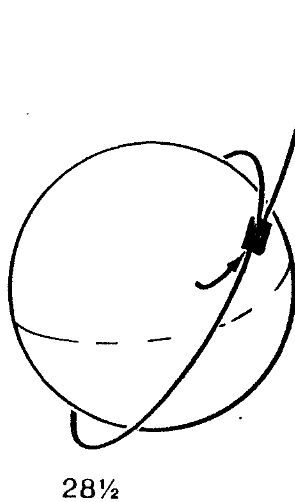
Man-tended free flyers
LEO

1 astrophys — 28½°
1 MTLS pro — 28½°
1 earth obs — 57°
1 earth obs — 90°
(DoD not shown)



OTV basing

1 to 2 commun sat./yr — GEO
1 planetary sat./yr — ESC
1 Earth obs — HEO
2 to 3 nat'l sec sat./yr



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The accommodations for the mission equipment required for the initial phase will require expansion in all areas of operation to accommodate an expanded set of missions.

The Man-Operated Function missions are augmented by increased Life Sciences research, Environmental Observations and addition of major Earth and Planetary mission equipment. Mission requirements in Astrophysics increase to accommodate additional telescopes. Communication and Technology Development are expected to continue from the initial phase, requiring capability to assemble and operate much larger elements.

The quantity of free-flyers increases to 1 to 2 spacecraft in each orbit inclination, potentially using LEO platforms where warranted to group sensors and share services.

The OTV Basing Function grows to meet launch and service requirements for 8 DoD satellites per year, 12 to 20 communication satellites to GEO each year, along with continued Planetary missions and the addition of Environmental Observation satellites to be placed at GEO.

SUMMARY OF MISSIONS — FINAL REQUIREMENTS (2000)

Man-operated 28½°
400-500 km

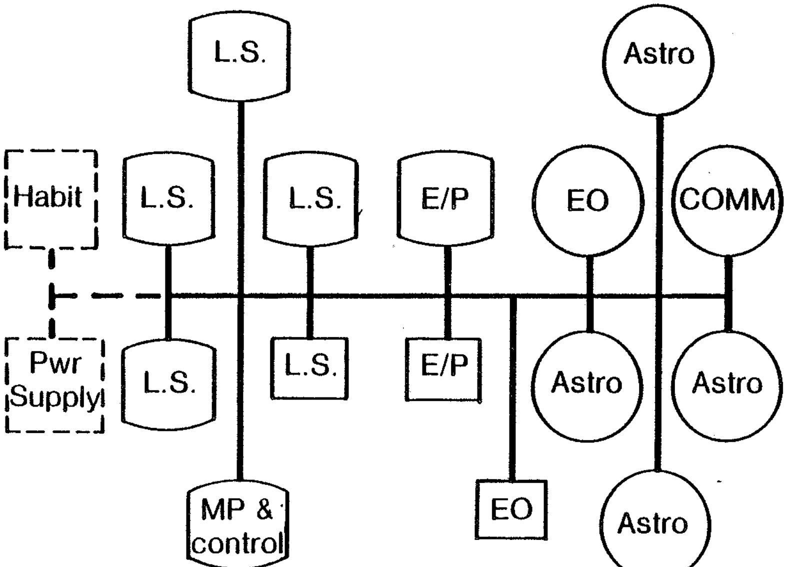
4 life science modules
1 earth/plan module
1 MP & P/L controls module
1 commun anten
4 astro telescopes
1 env obs anten
1 env obs pallet — 4m × 6m
1 earth plan pallet — 4m × 20m
1 life science pallet
10 to 12 P/L crew
60 to 80 kw avg
(DoD-R&D can be accommodated)

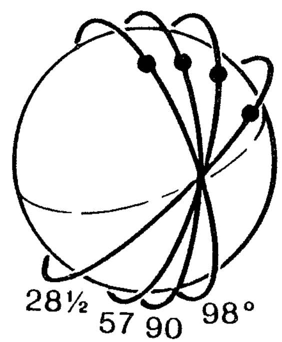
Man-tended free flyers
LEO

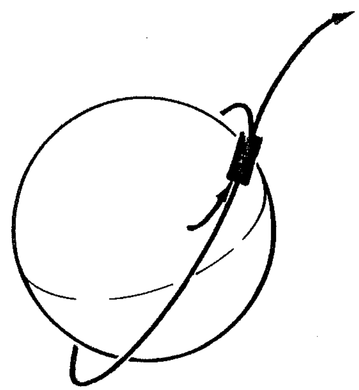
1–2 astrophys 28½°
1 mtl proc 28½°
1–2 env obs 57°
1–2 env obs 90°
2 env obs 98°
(DoD not shown)

OTV basing

12 to 20 commun sat./yr — GEO
1 weather sat. (set) — GEO
1 planetary sat./yr — ESC
1 Earth obs — HEO
9 nat'l sec sat./yr







Major benefits are indicated that are directly attributable to having man in orbit for extended time periods for the conduct of research, and for development of advanced technologies. These benefits will be realized in both low "g" research, and viewing Communications and Technology experiments missions.

Man's tending of free-flyers, either from a Shuttle or from space-based systems, provides benefits in quality of observations, and in extending the useful life of observatories.

Benefits of a performance nature resulting from OTV basing are primarily due to man's capabilities for on-orbit checkout and servicing of spacecraft prior to commitment to HEO and GEO missions. At later dates additional benefits may accrue from servicing of GEO spacecraft by man at LEO or by automated means at GEO.

SUMMARY OF PERFORMANCE BENEFITS

Function	Potential Benefit	Disciplines/Missions
Man-operated	• Scientific research requiring man's presence for periods exceeding 12 to 14 days	Life Sciences
	• Advanced technology development requiring man's presence over extended mission times	Communications Earth/planetary Env observations Materials processing
	• Assembly and servicing of large observatories in LEO	Astrophysics
Man-tended free flyers	• Increased quality of observations by on-orbit servicing of sensors & spacecraft	Astrophysics Envir observations
	• Increased useful life of observatories by update/changeout of sensors, replenish consumables	Astrophysics
OTV basing	• Increased quality & reliability of spacecraft systems by checkout, servicing and deployment, prior to commitment to GEO	Communication Planetary Envir observations
	• Increase in technical performance of spacecraft by on-orbit assembly & checkout in LEO of multi-shuttle flight systems	Environ observations

15112793-112

Major economic benefits in the man-operated function are due to the man-operated labs being continuously in orbit, thus requiring launch of only the crew and consumables, specimens and updated lab equipment to conduct the research desired. This reduces cost compared to flight of a Spacelab mission for each research/development activity.

The servicing of free-flyers in space by man from Shuttle has long been recognized as an economical means to achieve a long and useful life for very expensive observatories. Further growth to accomplishing this with space-based systems provides further economies in transportation costs.

A very major economic benefit is foreseen with the use of a space-based reusable OTV to transport spacecraft to GEO and HEO orbits. This greatly reduces launch costs since only the spacecraft must be launched aboard the Shuttle from earth and reuse of the OTV reduces transportation costs to HEO/GEO. OTV propellants offer potential for delivery to LEO in more economical ways than in an upper stage to the spacecraft. Secondary but still significant benefits are projected as a result of the capability for checkout and servicing of spacecraft prior to launch to GEO, and subsequent servicing in-situ or by retrieval.

SUMMARY OF ECONOMIC BENEFITS

Function	Potential Benefit	Disciplines/Missions
Man-operated	• Launch cost savings possible by on-orbit lab for permanent or visited manned vs multiple shuttle/spacelab missions • Reduced cost of equipment in manned lab with capability to adjust, repair, modify, as needed, vs cost of fully automated equipment	Communications Earth/planetary Env observations Materials processing Life sciences
	• Earlier returns with reduced risk for advanced technology results incorporated into operational spacecraft systems — reduced time to commercialization	Communications Materials processing
Man-tended free flyers	• Reduced payload launch cost possible by less spacecraft volume/mass allocated to storage of consumables & system redundancy • Reduced spacecraft cost by life extension & relaxed reliability made possible by retrieval repair & service capability in LEO	Astrophysics Env observations
	• Reduction in spacecraft fabrication, launch & servicing in LEO costs by grouping of sensors onto platforms	Env observations
OTV basing	• Reduced launch cost with OTV in LEO • Reduced launch costs by reusable OTV • Reduced spacecraft cost due to checkout, adjustment & repair in LEO, prior to commitment to HEO, GEO & escape missions	Communications Planetary

15112793-113

During the next phase of the study major attention will be given towards increasing the participation of potential users of a Space Station, particularly in the commercial and international areas.

Mission requirements will be further defined in areas that have a major influence on station architecture, cost, or benefits/savings. This will be done in conjunction with users where possible.

Mission analyses will be conducted primarily to time-phase the mission activities to derive a more accurate estimate of mission accomplishment, and requirements for station support and resources.

Spacelab modules will be examined vs station mission requirements to estimate the potential for use of these labs on the station.

A significant effort will be devoted to quantifying the performance and economic benefits derived by meeting mission requirements on the Space Station.

REQUIREMENTS STUDIES — NEXT PHASE

Pursue user involvement
- Commercial — follow up for response
- International

Continue validation, expansion & definition of mission requirements

Expand requirements analysis to facilitate architecture trade studies
- Resource requirements — crew, power, data
- Free-flyer servicing requirements
  - Orbits, equipment serviced & intervals
- On-orbit assembly & service requirements of large LEO free-flyers & OTV spacecraft
- Contamination & g disturbance constraints

Examine spacelab laboratories' capabilities vs space station research mission requirements
- Mission timelines — manned activities
  - Viewing/orientation time sharing

Quantify performance & economic benefits

A manned Space Station will provide major performance and economic benefits to a wide range of missions planned for the early 1990's. Most of these missions require, prefer or will accept a 28.5°, 400-500 km orbit. The balance require higher inclinations and generally become operational in mid-decade.

Free flyers, which do not lend themselves readily to a manned Space Station because of their particular requirements, will be operational throughout the decade. These occur at a variety of orbits and altitudes but many fit the expected 400-500 km Space Station orbit. Providing periodic service to these free flyers will improve their performance output, enhance their cost effectiveness and probably reduce total cost as well.

Development of a man-operated OTV base provides the most significant and the most quantifiable economic benefits. Economic benefits quantified to-date exceed 1.3 billion dollars per year, offering potential for rapid payback of Space Station investment.

Man-operated facilities for commercial activities such as materials processing, communications, and earth/ ocean observations have a tremendous economic potential - quantification is more difficult. Commercial interest in a Space Station does exist but extensive user interaction is necessary. An in-place facility (or firm availability date) will provide a major stimulant to potential commercial users.

Combined NASA/DoD utilization of an initial Space Station provides economic and technical benefits. Preliminary studies of operational DoD missions indicates a need for a separate station(s). Continued discussions are expected to develop major operational uses and benefits of a Space Station to DoD.

MISSION REQUIREMENTS SUMMARY

- Large number of early time period missions suitable for a 28½-deg, 400-500 km station
- Smaller number at 57 deg & polar in later time period
- Free-flyer servicing requirements at 28½ deg, 57 deg & polar orbits throughout time period
- Sufficient OTV traffic identified to support early implementation
- Commercial market needs further development
- Mission requirements activities to date provide rational basis for architectural option evaluations

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SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS
Midterm Briefing

	Presenter
Introduction	Don Charhut
Executive Summary	Otto Steinbronn
Mission Requirements	Warren Hardy/Dick Norris
Approach & Data Base	
Mission Requirements	
Integrated Mission Requirements	
Summary of Mission Requirements	
Mission Implementation	John Bodle
Cost & Programmatic Analysis	Bob Bradley
Summary	Otto Steinbronn

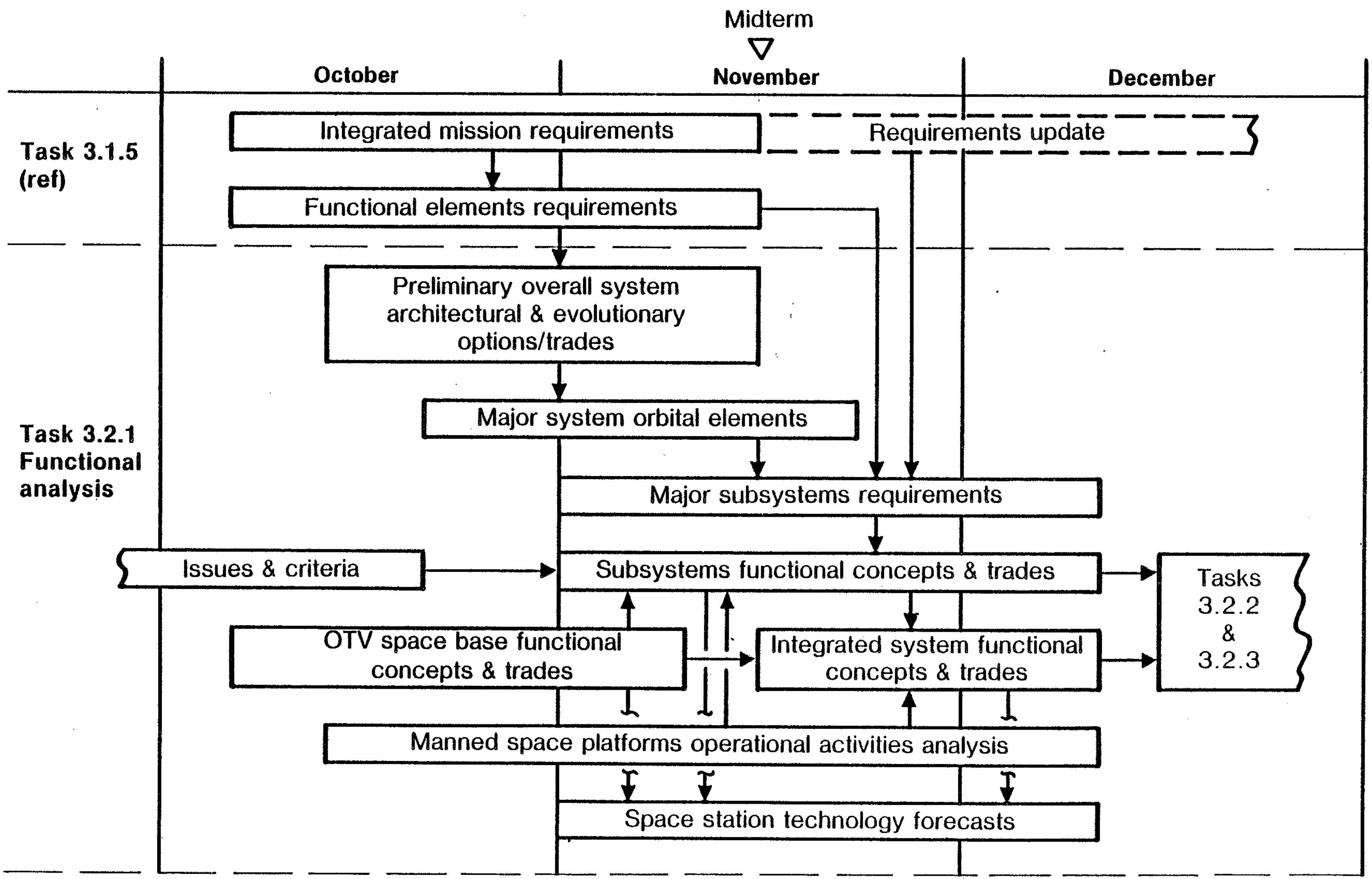
15112973-7

The Missions Implementation Task initially focuses on a thorough functional analysis which synthesizes functional elements requirements into system and subsystem functional concepts that can be used to define architectural options for Space Station. This effort has been paced by the acquisition of missions requirements during the initial study phase.

To date we have concentrated on identifying issues affecting system architecture and criteria for evaluation of alternative functional concepts in each of the subsystem and system areas. We have defined top level functional element architecture based on the functional elements requirements developed from the mission requirements. Major system orbital elements have been tentatively established along with three preliminary evolutionary program options. We have defined functional concepts for an OTV Space Base, as well as a concept of a Space Based OTV.

This initial task will be completed as shown on the facing chart, major subsystems requirements will be defined to allow subsystems functional concepts to be developed and evaluated. The manned space platform operational activities analysis will allow us to establish preliminary requirements for crew size, crew tasks, crew timelines, crew equipment, automated elements and system arrangements, to support the definition of subsystems and system functional concepts. Selected concepts will then be used to identify new technologies requirements and develop Space Station architectural concepts.

SPACE STATION MISSIONS IMPLEMENTATION APPROACH
Initial Task



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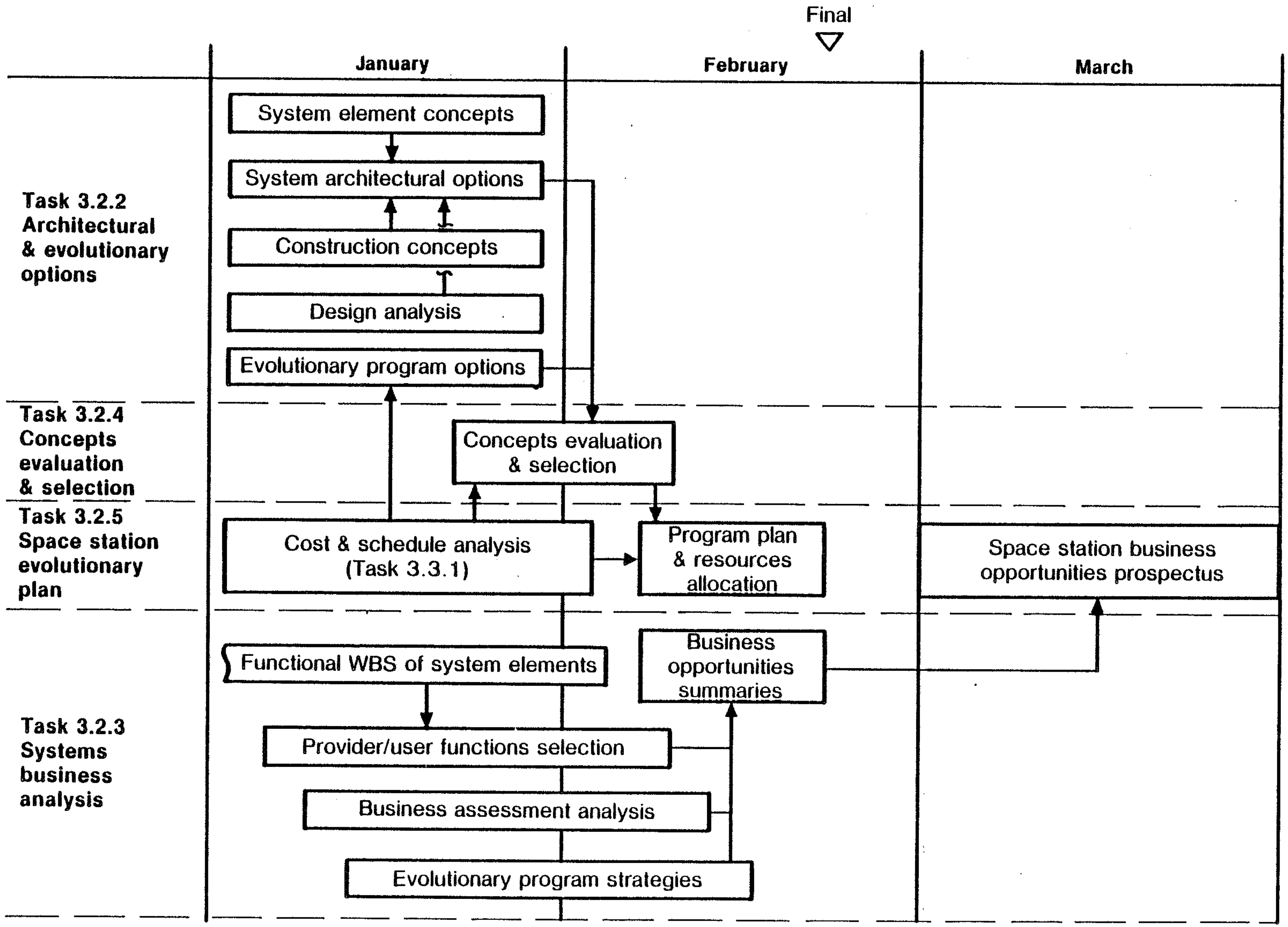
The final missions implementation task will include the definition of Space Station System architectural options, evaluation of these options, selection of a preferred option and development of a program plan and ROM program costs for the preferred option.

In addition, we plan to perform a systems business analysis which will identify the potential business opportunities available to industry, either as a provider of Space Station elements or as a user of Space Station elements. For example, a provider function could include such elements as; 1) an OTV; 2) a general purpose laboratory module; 3) a data processing system, etc. These functions would generate revenues which would give the provider a return on investment through several possible institutional arrangements between government and private industry.

The systems business analysis will create and evaluate institutional options as well as explore other methods by which the government can encourage private development of Space Station functions. These analysis will then be used to formulate evolutionary program strategies driven by specific business opportunities. These opportunities will be defined for prospective entrepreneurs and documented in our Space Station Opportunities Prospectus.

SPACE STATION MISSIONS IMPLEMENTATION APPROACH
Final Task



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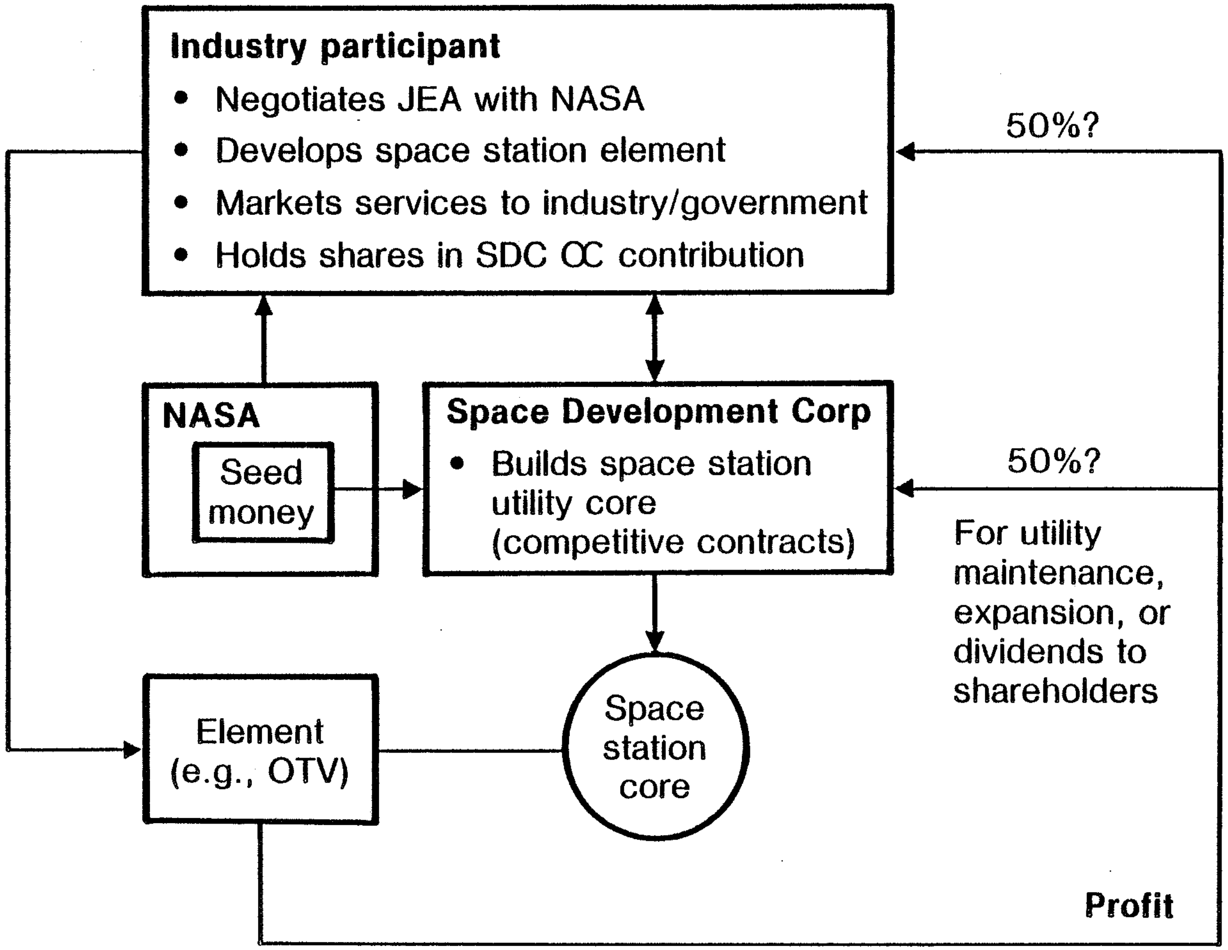
Formation of a quasi-government "Space Development Corporation" is one possible means of involving private industry in development of a manned Space Station. NASA would provide seed money to the Space Development Corp. (SDC) for establishment of core Space Station facilities, procured through competitive contracts. Private companies would "buy into" the SDC by investing in marketing and operating functional Space Station elements, such as a space-based OTV. NASA could negotiate separate Joint-Endeavor Agreements (JEA) with developers of Space Station elements to reduce barriers to investment. Some portion of the industry participants' profits from operation of Space Station elements would be returned to the SDC for reinvestment in Space Station utilities, or dividends to SDC shareholders. The SDC would work with NASA to integrate the various Space Station elements, and would represent the interests of the public-at-large as well as all participants in the Space Station program. Its directors would come from government and the ranks of SDC shareholders. Key advantages of this plan are its potential for meaningful industry involvement, market responsiveness, and competitive efficiency.

The following criteria will be used to evaluate the institutional options:

- Responsiveness to industry and government markets
- Social costs and benefits
- Compatibility with requirements and funding capabilities of various user groups
- Optimization of private-sector involvement
- Overall system efficiency (cost and performance)
- Maximization of long-term options for space development

SPACE STATION INSTITUTIONAL OPTION



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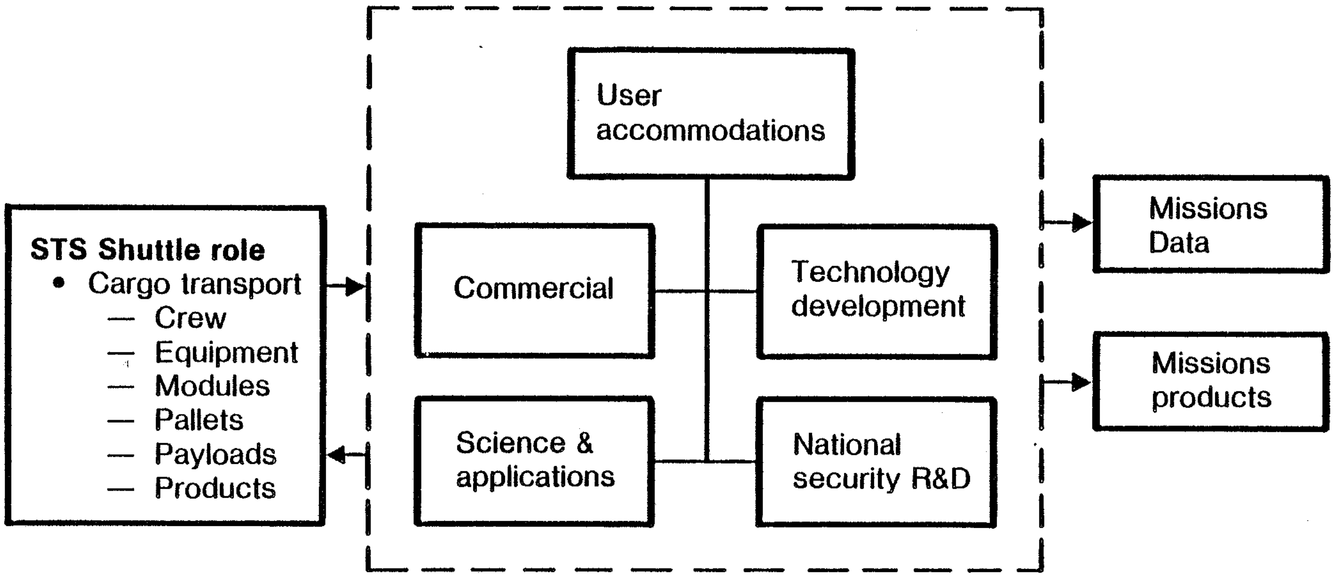
The mission requirements task identified three major functions that Space Station will perform. The first of these is the man-operated function which basically provides the facilities, interfaces, resources, orientation, environment, and permanent manned presence necessary to perform long term man-operated missions in space.

The top level architecture of this function consists primarily of user accommodations supporting the four major communities of users. This functional element is supported by the core functions of the Space Station orbital elements into which it is integrated. It receives its crew and hardware via the shuttle. Its principal outputs are missions data and products.

Mission requirements indicate a need for this function as early as 1990.

MAN-OPERATED FUNCTION ARCHITECTURE

- **Functional elements**



- **Requirements**

Orbit	
• Inclination	28½ deg
• Altitude	400—500 km
Crew size	
• Initial	4-6 persons
• Final	10-12 persons
Orientation	TBD
IOC	1990

15112793-127

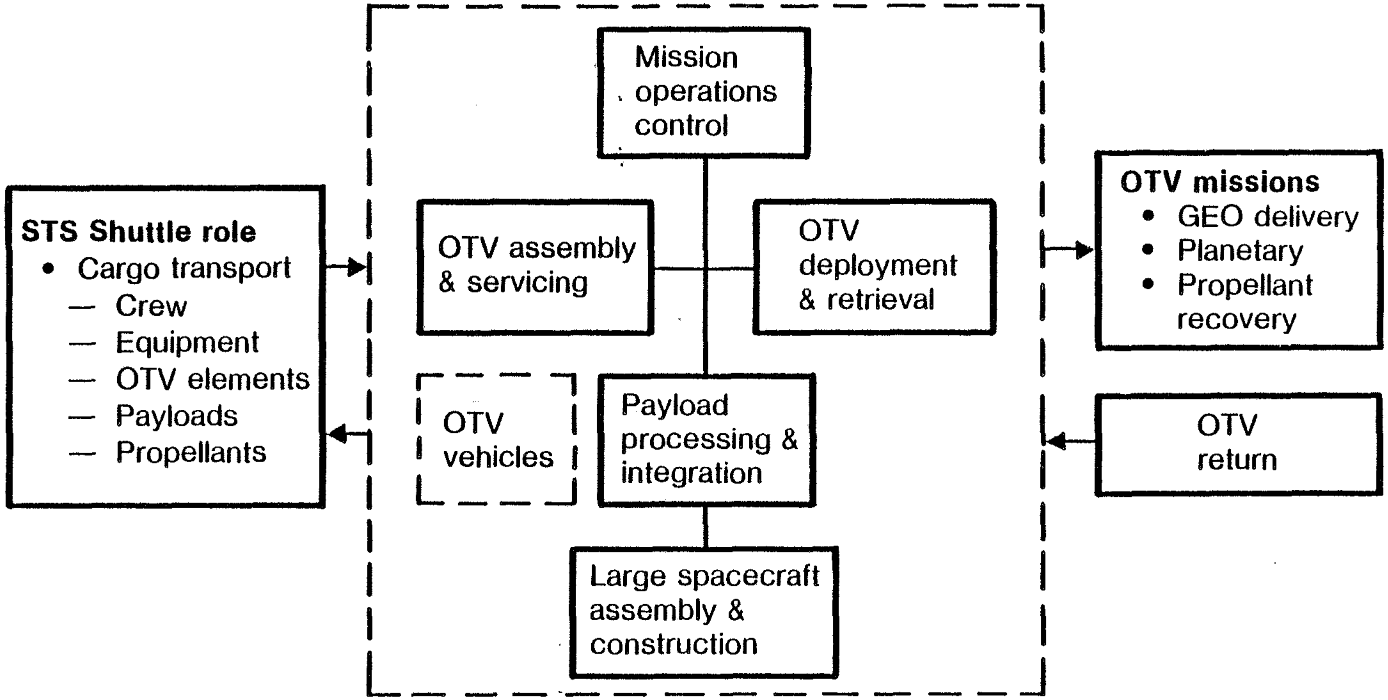
The second of the major Space Station functions identified is the Orbital Transfer Vehicle (OTV) base. The architecture of this function includes these elements

Mission Operations Control	-	Provides remote control and monitoring of functional elements shown through all phases of operation.
OTV Assembly and Servicing	-	Includes all elements required to protect, support, inspect, assemble, checkout, store and transfer propellants and fluids, maintain and repair the OTV.
OTV Deployment and Retrieval	-	Includes all elements required to separate the OTV and its payload from the station for flight and to dock or berth the vehicle with the station.
Payload Processing and Integration	-	Elements required to handle, support, protect, inspect, install the payload on the OTV, and checkout the payload prior to launch.
Large Spacecraft Assembly and Construction	-	Elements required to handle, support, assemble or fabricate, checkout, repair and service large spacecraft. Note: This function could be included as part of any of the three major functions.

This function receives its crew and hardware via the Shuttle. Its principal output is placement of spacecraft in GEO, space launch of planetary missions and mission to recover propellants from the Shuttle external tanks as discussed later.

OTV BASE FUNCTIONAL ARCHITECTURE

- **Functional elements**



- **Requirements**

Orbit	
• Inclination	28½ deg
• Altitude	370-400 km
Crew size	
• Initial	~ 8 persons
• Final	~ 12 persons
Orientation	TBD
IOC	1994-1995

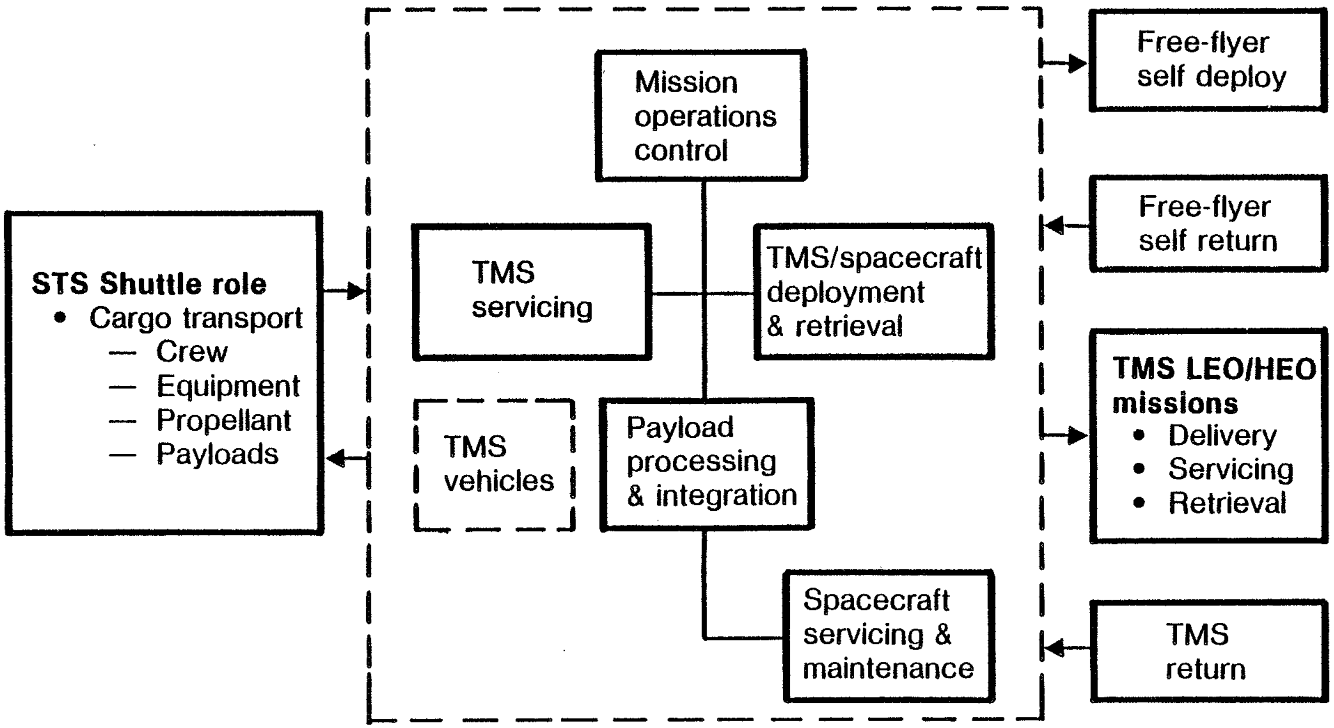
The third major function of Space Station is the man-tended free-flyer function. Its purpose is to service and maintain free-flying spacecraft periodically or whenever failures occur. This function can be performed by the shuttle until the number of tended free flyers in LEO and HEO warrants a permanent manned space based function to handle the demand.

The functional elements required for this function are similar to the OTV base. A spacecraft servicing and maintenance function is included to allow retrieved spacecraft to be man-serviced and maintained on-board the station.

A Teleoperator Maneuvering System (TMS) will be used to deliver and/or retrieve free-flyers from LEO or HEO orbits near the plane of the station orbit. The TMS may also be configured to perform in-situ servicing of free flyers by automated techniques. By combining the TMS and OTV, it will be possible to retrieve and/or service spacecraft in GEO or in out-of-plane LEO orbits.

MAN-TENDED FREE-FLYER FUNCTION ARCHITECTURE

- **Functional elements**



- **Requirements**

Orbit	
• Inclination	28½ deg
• Altitude	~ 400 km
Crew size	3-4 person*
Orientation	TBD
IOC	TBD

*Depending on traffic

Grouping of the major manned functional elements was evaluated on a preliminary basis to provide a rationale for the number and functions of manned stations that may be required to meet the mission requirements. These trade-offs will be analyzed in more detail during the remainder of the study to substantiate the assumed potentials indicated.

Combining all three functions on a common manned station would minimize equipment and operating costs because a common core function could be used, crew functions could be shared, and the logistics, STS and ground support functions would be simplified. However, many of the laboratory functions requiring very low g, low contamination environments would be penalized by frequent dynamic disturbances and contamination generated by OTV, TMS and more frequent Shuttle docking activities. Orbital altitude required for man-operated functions may conflict with the lower altitude desired for Shuttle resupply missions. More operational conflicts could occur due to the demand on core functions for power, data processing, communications, etc. The ever-growing missions needs of the three functions would soon reach practical limits.

Combining the OTV and FFT functions on one station and placing the man-operated function on a separate station would be more costly, but would resolve the major conflicts previously described. The OTV and FFT have many areas of commonality and could operate in a lower altitude more accessable to the Shuttle without OMS kits. The MOF could be maintained in a higher altitude, less frequently visited by Shuttle or could be resupplied periodically from the OTV/FFT station using the TMS.

Combining the FFT and MOF functions is seen to offer few advantages.

MANNED FUNCTIONAL ELEMENT GROUPING OPTIONS
Preliminary Comparison

Trade-offs	Assumed Potential		
	All Functions Combined OTV FFT MOF	Separate Man-Operated Function OTV FFT / MOF	Separate OTV Base OTV / FFT MOF
• Equipment cost*	Lowest	Medium	High
• Operating cost*	Lowest	Medium	High
• Impacts on lab functions	High	Low	Medium
• Orbit requirement conflicts	Medium	Low	Low
• Operational conflicts	High	Low	Medium
• Growth limitations	High	Low	Medium
Conclusions	**Low cost/high risk**	**Best overall**	**Few advantages**

*Due to commonality

OTV = OTV base
FFT = Free-flyer tending
MOF = Man-operated function
All functions at 28½ deg incl

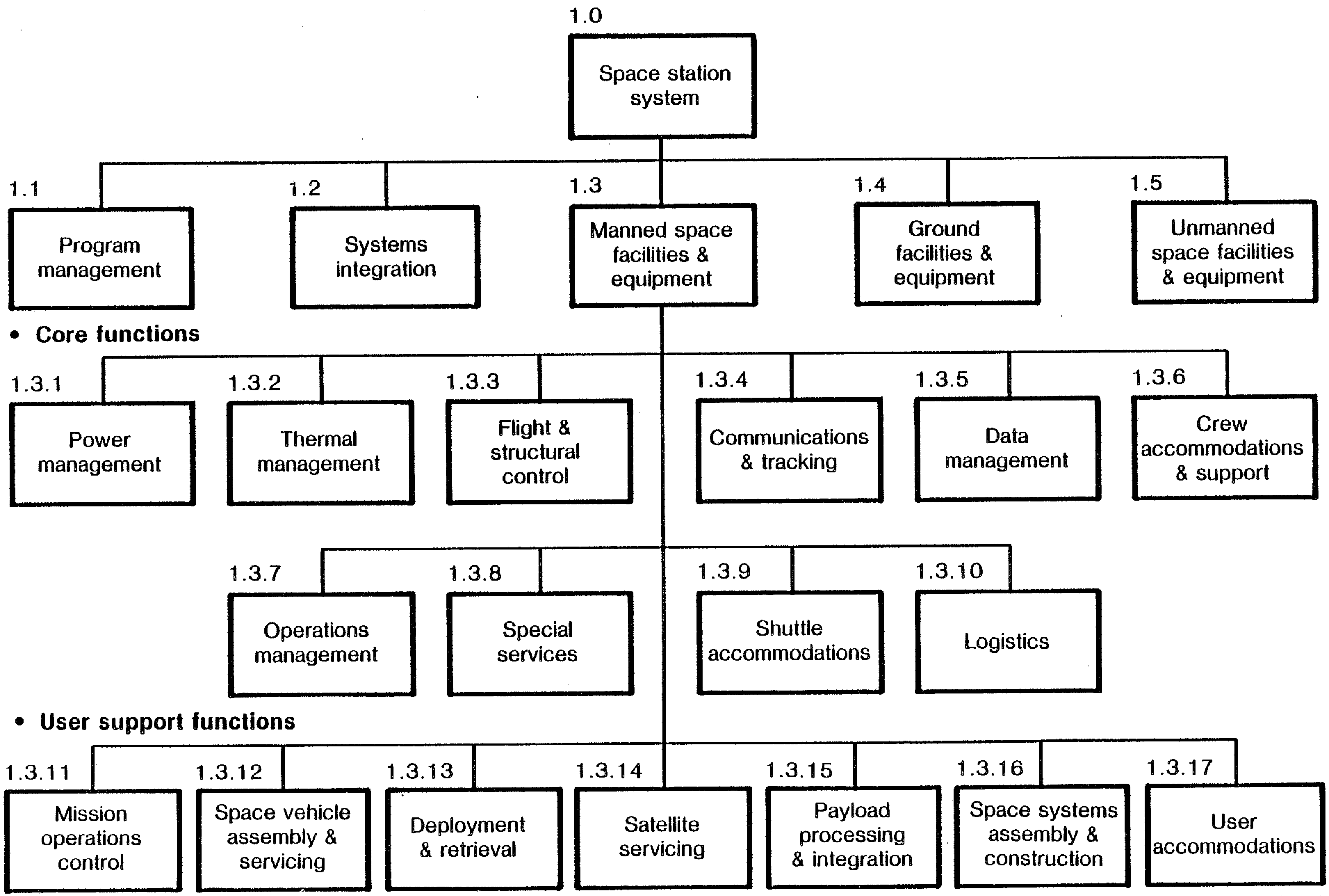
15112793-111

The functional elements of Space Station are identified in this preliminary WBS/system breakdown. The Space Station System that will form a part of the overall space infrastructure has five top level functional elements as shown. As the numbers of and missions of the manned and unmanned facilities are determined, this breakdown will be expanded to allocate appropriate core and user support functions to each facility. This is necessary because the requirements for each major space facility will vary. This may drive the architecture and technology for a particular functional element, e.g., power management, flight control, etc., toward a different solution in each case.

We will address major issues associated with the system and each of its functional elements and trade-off alternative concepts and technologies in order to arrive at a preferred architecture and identify new technology needs. Through this effort we will explore unique approaches for satisfying functional requirements wherever possible. For example, we recognize that the expendable E.T. is a valuable resource. We are very close to the NASA-funded study at UCSD and will be evaluating possible immediate uses of the E.T.

We also have a subcontract with Spacecom Corporation to aid us in assessing the impacts of Space Station on the TDRSS and identifying the needs for future growth in its space and ground segments.

PRELIMINARY SPACE STATION WBS/SYSTEM BREAKDOWN



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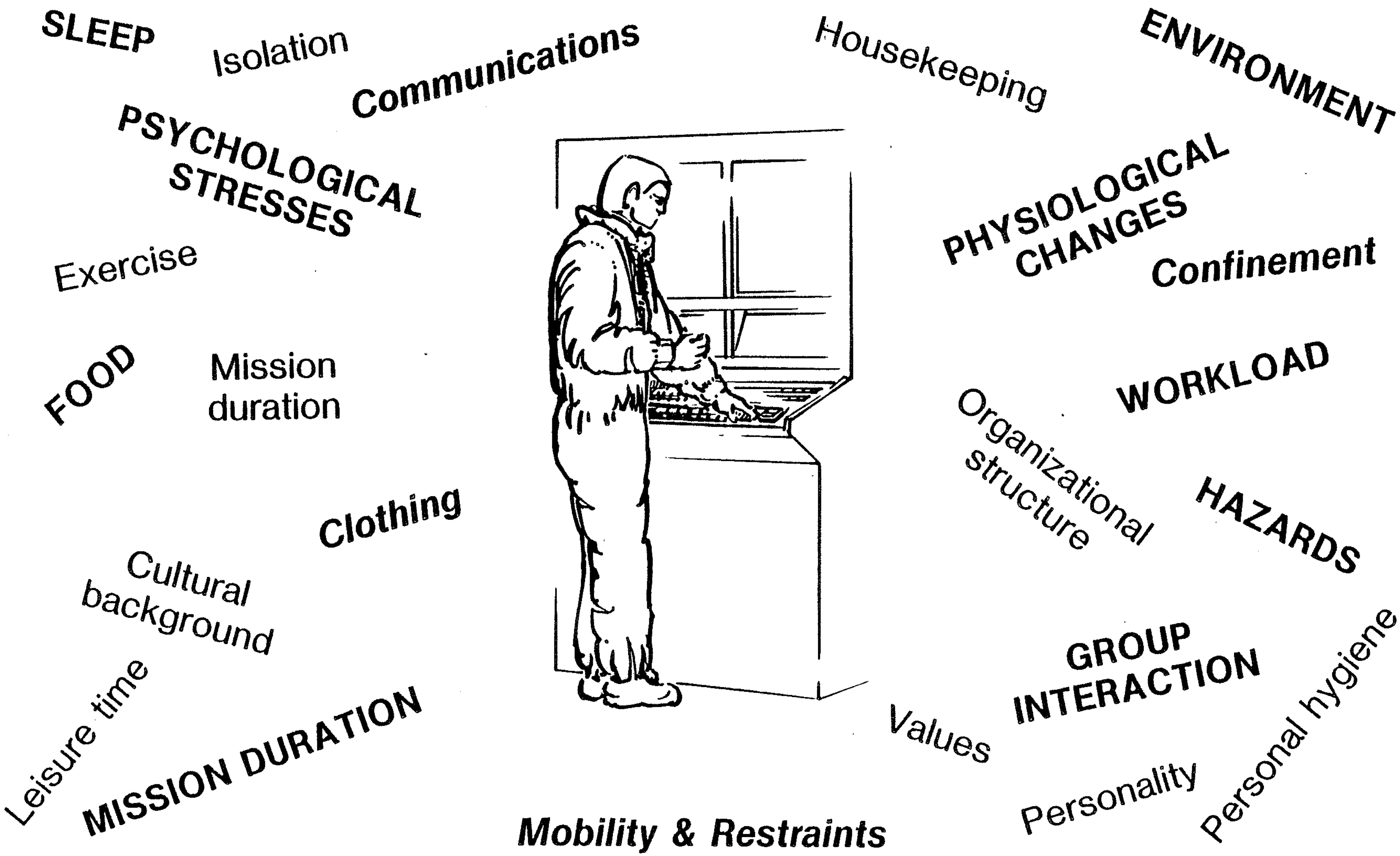
Because the human will play an integral role in every facet of the premanently manned station, we will place a great deal of emphasis on the human aspects of functional element architecture. In each element of the system we will consider the needs, limitations, interactions and stresses imposed on the human by the system and identify architectural options that will assure the health and well-being of the crew members.

EXTENDED HUMAN PRESENCE DRIVES ARCHITECTURE



15112793-149

An OTV optimized for the space environment will differ greatly from its ground based counterpart and will offer significant advantages. A wide range of OTV concepts address the key issues shown. A NASA Headquarters/MSFC concept with many good features such as spherical tanks is shown on the lower right. Our baseline vehicle, illustrated on the upper left, will serve as a basis for comparison and economic analysis in this study. IRAD studies in 1983 will further define Space-Based OTV configurations.

The OTV baseline is designed to meet all requirements of the MSFC Nominal Mission Model, Rev. 6, October 1982. The two tank aerobraked OTV is capable of delivering 1) 11,000 lbs to GEO (from a 220 nmi x 28.5° station orbit) and returning empty; or 2) 16,500 lb in an expendable mode (no aerobrake); or 3) 5,900 lbs up-and-back; or 4) ascend empty and return with a 12,500 lb payload. With four tanks these capabilities increase to 28,700, 35,000, 15,400 and 33,000 lb, respectively.

The baseline OTV utilizes an advanced 10,000 lb thrust expander-cycle engine. The engine is specifically designed for space maintenance so that return flights to Earth are minimized. The engine is throttlable to limit nominal payloads to <0.25 g acceleration at burnout. A kit modification could allow the engine to be operated in pumped idle mode at $\leq 1,000$ lb thrust with only a minor performance loss. A dedicated low thrust engine with higher performance and other benefits (lower weight, use of subcoolers, etc.) is also being studied for application to the OTV. Dual engines and/or an enhanced RCS capability would be used on a manned mission with greater reliability requirements.

The OTV modular tankage is designed for flexibility to suit the mission requirements. Each tank has separate vessels for oxygen and hydrogen separated by low conductive struts and insulated by MLI. Usage of <0.5 psia vapor pressure propellants and an advanced space engine with low inlet pressure and NPSH requirements combine to reduce tankage required skin guages. Use of a low thrust engine and/or a throttable high thrust engine reduces acceleration loading on the tanks and further improves their efficiency. Each tank contains 14,200 lbs of propellant @ 6:1 LO_2 to LH_2 ratio and has a total propellant mass fraction (including residuals) of 0.97.

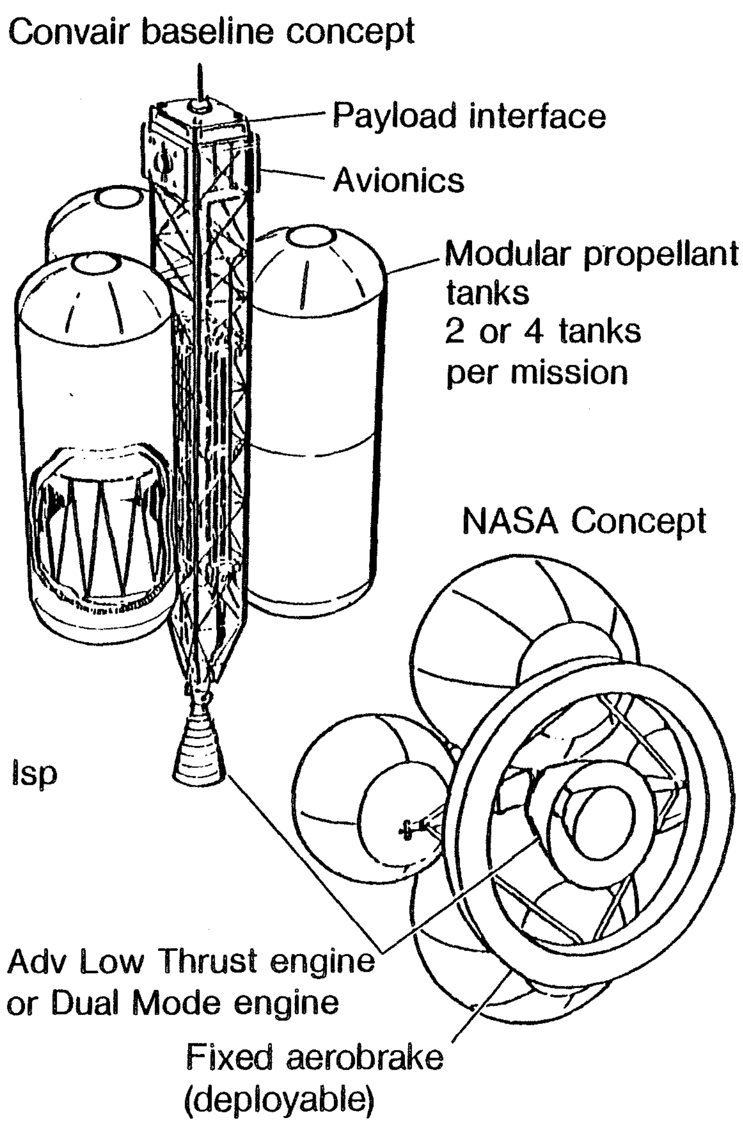
A center core structure carries all axial loads. The engine and fixed aerobrake (not illustrated) are mounted below the tanks to reduce engine plume effects. The Guidance & Navigation, Communications, and Attitude Control subsystems are mounted to the core structure, as well as most of the electrical and pressurization systems. A docking adaptor at the forward end attaches to the payload, manned module or payload servicing module. Modular avionics and other subsystems simplify servicing.

SPACE-BASED OTV

Advantages
- Free from Shuttle constraints (size, loads)
- Reusable (lower cost)
- Modularity (mix & match capability)

Key issues
- Long-term space exposure
- Orbital integration, servicing
- Efficiency (low weight, high Isp)
- Low-cost operations (propellant delivery to LEO)
- Deployment & retrieval
- Future payloads & mission characteristics

Technology needs
- Lightweight (thin gage) tanks
- Lightweight (composite) structure
- Lightweight/high temperature aerobrake materials
- Long life/space maintainability engine (low weight, high Isp
- Cryogenic propellant management — thermal control (MLI insulation, mixing, venting), propellant acquisition gaging
- Meteoroid & space debris protection
- Redundant, fault-tolerant, hardened avionics
- Auto rendezvous/docking



15112793-103

This graph illustrates the potential performance and cost benefits of a Space-Based OTV as compared to Shuttle-Centaur and one documented Ground Based Reusable OTV concept. These benefits are the result of 1) the higher mass fractions achievable by optimizing the design for space environment (see preceding chart); 2) decoupling of the system from the STS Orbiter manifesting costs and constraints; 3) mix-and-match capability to use either two tank or four tank sets depending on payload mass; and 4) reusability.

Payload delivery costs for the Shuttle-Centaur and the Ground Based Reusable OTV are computed for a generic STS lift capacity of 69,000 lbs, the average capacity of the four Shuttle Orbiters now planned. It is assumed that both systems would require dedicated Shuttle missions since the payload-upper stage combination represents more than 75% of payload bay length/payload lift capacity for most payloads.

The Ground Based Reusable OTV is derived from the OTV Concept Definition Study, 3/81, Contract #NAS8-33533, Report #GDC-ASD-80-012. An RL10 Cat. IIB engine was selected for the OTV in that study. Use of the higher performance Advanced Space Engine (Isp = 482 vs 463) as used for the space-based OTV would reduce GEO payload delivery costs by about 10%, while increasing payload lift capability. In all probability, the payload manifesting efficiency for the ground based systems will be $>$ 80%.

Payload delivery costs for the Space-Based OTV include $16.75M non-recurring cost amortized over 60 flights, operating costs for each flight, and the costs to deliver the propellants and the payload to LEO. Payload delivery cost vs payload weight curves are shown as a function of propellant delivery cost to LEO for the two tank and four tank versions. Since the OTV return from GEO may be either by all propulsive or aerobraked ΔV change, both techniques are compared using the maximum propellant delivery cost of $1,200/lb. Missions that include the return of a payload from GEO are not shown.

It is clear that maximum cost benefits can be achieved by reducing the cost of propellant delivery to LEO. Techniques to accomplish this are shown on the next chart. Other benefits to STS users are discussed in the Cost and Programmatic Analysis section.

GENERAL DYNAMICS
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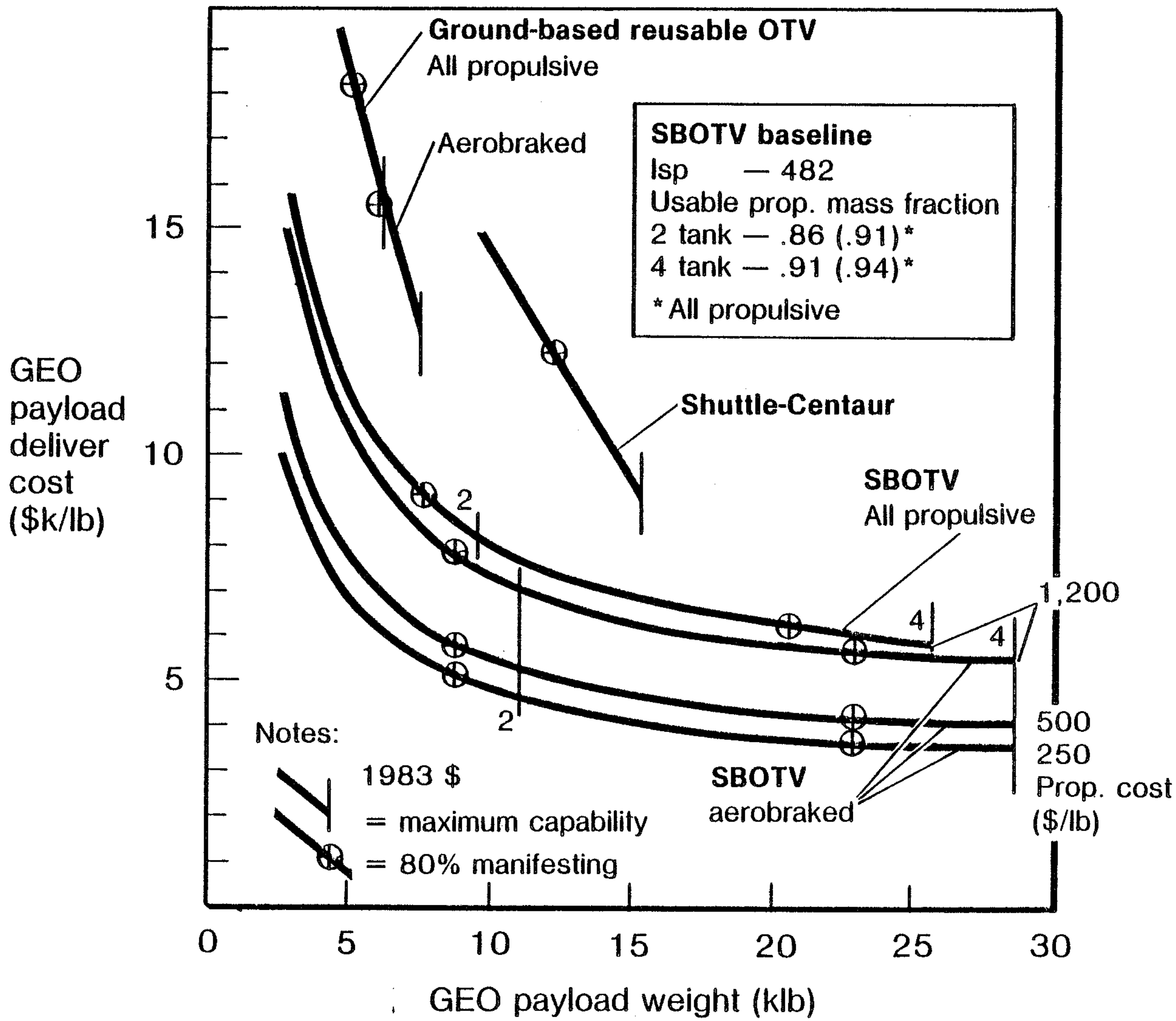
OTV PERFORMANCE COMPARISON
Payload to GEO Only



15112793-148

Low cost propellant delivery is key to realizing the substantial cost benefits possible with a Space Based OTV. A wide variety of concepts have been proposed for delivering propellant to orbit for less than the STS average delivery cost ($\approx$\$1200/lb). Most can be divided into two categories, those which utilize External Tank (ET) residuals and those which utilize a Shuttle Derived Vehicle as a transportation tanker.

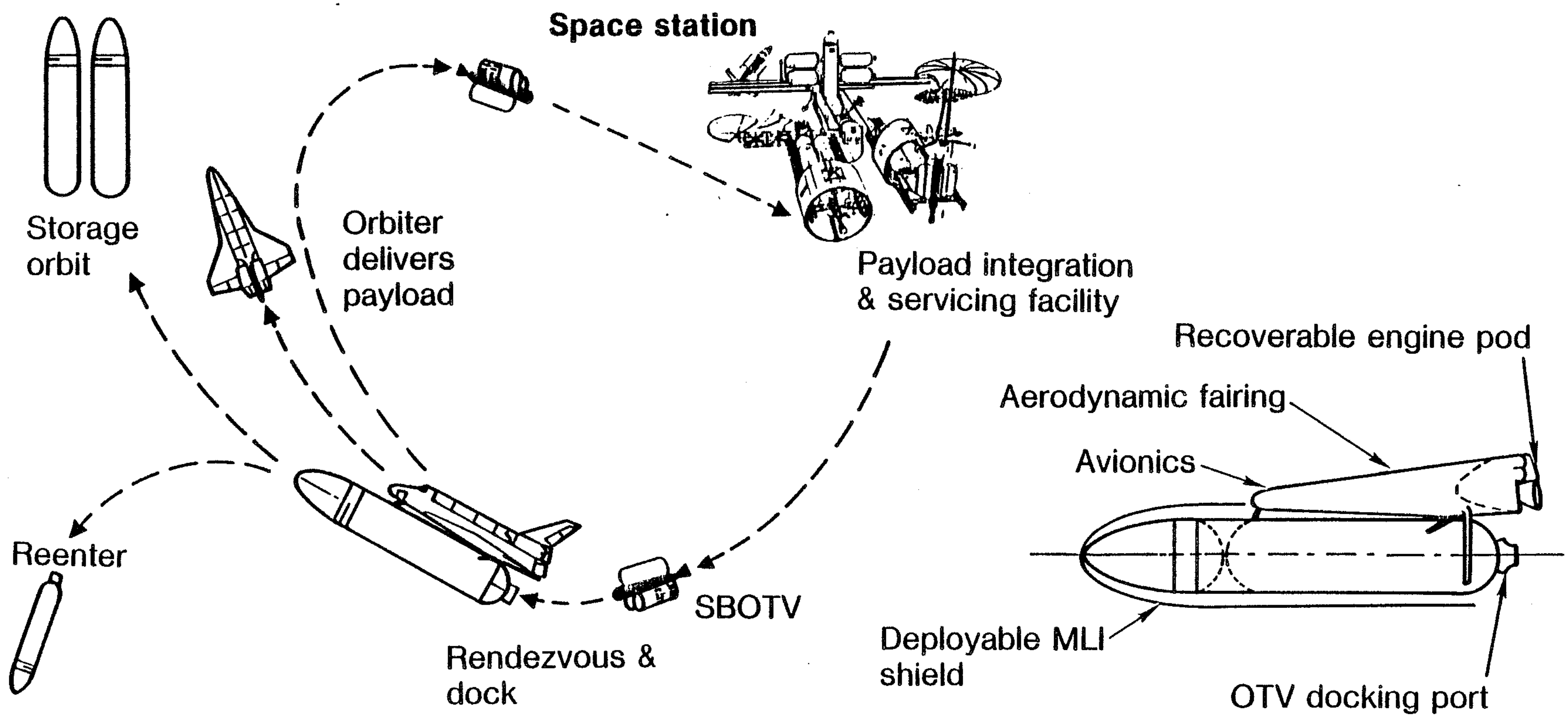
The Honebee Concept utilizes the automatic rendezvous and propellant loading/unloading capabilities of the OTV to directly off-load residuals from the ET. By directly loading propellants into the OTV within 45 minutes after MECO, boil off losses are reduced (especially H_2 losses) and the added complexity of separate tankage in the orbiter is eliminated. An OTV docking port is located in the aft end of the ET. This port receives propellants from the H_2 tank directly and the O_2 through a small duct connected to the main SSME feed line upstream of the Orbiter/ET interface. The OTV docks to the port and extracts as much propellant as possible while its engine provides the necessary settling thrust. Afterwards, the ET can either be deorbited or placed in a storage orbit by the OTV.

Propellants can be extracted from most shuttle flights from KSC, not just those going to the Space Station. This is because the OTV can maneuver to intercept the Orbiter/ET instead of relying on the orbiter directly docking with the Space Station to offload propellants from a payload bay dewar.

Nominal propellant residuals at MECO are about 9,400 lbs. at a ratio of 2 or 3 to 1. With +3 Sigma residuals ($\approx$5,500 lbs.) and nominal 0.75 payload manifesting efficiency ($\approx$17,000 lbs. additional) about 32,000 lbs. of propellants can be recovered per flight. For more volume limited payloads this could increase to almost 50,000 lbs. By suitable adjustment of the ET tanking procedure the desired 6 to 1 ratio of O_2 to H_2 residuals could be achieved.

The ET Tanker concept offers several advantages over other Shuttle Derived Vehicles designed for propellant carriage. Chief among these is the use of the ET to carry the propellants, thereby obviating the need to qualify a new set of large cryogenic tanks. The engine pod could either be recovered ballistically or returned in the shuttle cargo bay after disassembly at the Space Station. Similarly, the onboard avionics could be designed for reuse. The deployable MLI shield may be eliminated if the ET propellants are immediately off-loaded into a Space Station propellant depot rather than using the OTV Honeybee concept.

LOW-COST PROPELLANT DELIVERY CONCEPTS



Honeybee concept
- 9-36 klb residuals recovered per STS flight
- Propellant delivery cost — essentially free (no tanks in Orbiter)
- Supports 90-129 klb year to GEO

E.T. tanker concept
- 214-220 klb delivered per flight
- Propellant delivery cost — ≈235 $/lb
- Supplements Honeybee concept to support 360 + klb year to GEO

15112793-107

In principle, clusters of External Tanks can be cable connected to form a gravity gradient stabilized assembly 20 Km. or so long. The dimensions, weights, loads and stresses estimated by Dr. Colombo have been checked well within an order of magnitude.

We question the idea of elevators running up and down the cables and feel that interactions between transverse loads due to Coriolis accelerations and transverse stiffness due to cable tension should be studied carefully.

In principle, it should be possible to transfer energy and angular momentum between orbital bodies so that their individual orbits can be changed without direct application of rocket thrust to each independently. If this is to be accomplished by a cable, energy must be dissipated by a brake as the cable is let out or supplied by a motor as it is reeled in. The total system orbital energy will then change by this amount. As pointed out by Dr. Colombo an initial start must be provided while reeling out.

The most serious fundamental questions that remain appear to be in the area of quantitative transient behavior. Just how quickly will oscillations be damped by tidal effects or by programmed control of cable motion? What angular velocities will be encountered during reel in? It is clear that angular momentum of the system must be maintained, but how will this be distributed between spin about system centroid and orbital rotation of centroid about the gravity field center? Can this distribution be controlled by programming the rate of reel in? How long will it take to perform reel-out maneuvers which cannot be speeded up by "pushing on the cable"?

If all fundamental questions can be answered successfully there remains a tremendous amount of work to devise methods for and prove feasibility of engineering implementation.

If all problems can be solved the tether concept could result in tremendous benefits for orbital maneuvering.

TETHER SYSTEMS

- Underlying theory of Dr. Colombo's proposals reviewed & verified
- Cable-connected clusters of E.T.s, as proposed, will be statically stable in circular orbit
- The concept that an E.T. will rise while a tethered Orbiter descends to low orbit for reentry does not violate laws of energy & momentum
  - An initial start must be provided
  - Cable brake will dissipate energy
- Relative motions & times estimated for docking checked
- Basic questions remain on quantitative transient behavior
  - How quickly are oscillations damped by tidal effects or programmed cable motions?
  - What motions are encountered when reeling in & out?
  - What is effect of Coriolis acceleration transverse loads on cables when elevators run up & down?
- Feasibility of implementation not addressed

15112793-131

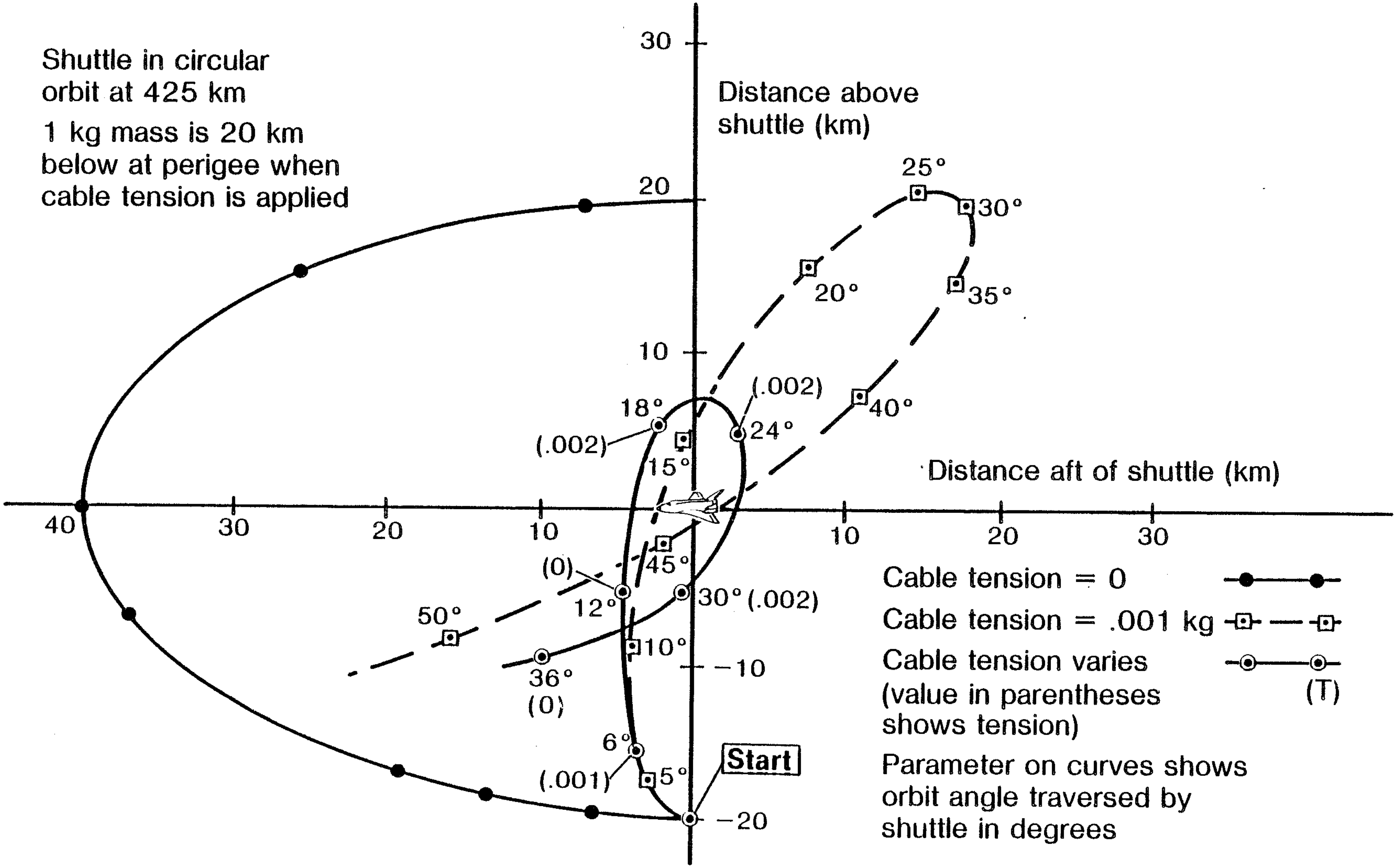
Chart shows motion of a 1 kg mass particle on the end of a massless tether cable relative to the Shuttle which is in a circular orbit at 425 km. Before cable tension is applied, the particle is at the perigee of an elliptical orbit which has the same period as the Shuttle and is 20 km below the Shuttle. Motion is shown with respect to a rotative frame attached to the Shuttle with the vertical axis passing through the center of the earth. Cable tension can be controlled as it is reeled in on a winch. Three cases are shown.

1. Tension is zero, so the ellipse of relative motion of two free bodies is seen.
2. Cable is reeled in with constant tension (.001 kg). Orbital angular position of Shuttle from the start is shown as a parameter. (e.g. 25°).
3. Cable is reeled in with varying tension chosen subjectively by the intuition of the operator. This is shown by parameter in parentheses - e,g, (.002 kg) tension.

These preliminary results indicate that relative motion can be affected by the cable, but some skill in programming the tension will be mandatory to achieve a smooth zero relative velocity final capture.

It is suggested that by applying tension in a judicial fashion with respect to inertial velocity of particle, it would be possible to change total energy and angular momentum of the particle in such a way as to come smoothly up to the orbital values of the Shuttle thus achieving a soft capture.

EXAMPLE OF TETHER TRAJECTORIES RELATIVE TO SHUTTLE



15112793-156

Based on our preliminary functions grouping comparison it appears likely that a minimum of two permanent manned stations would be required in the 1990 to 2000 time period. If we consider only the requirements that have been compiled thus far and take them at face value, we see a program option, shown here, that starts with the first manned station, operational in 1990, for man-operated functions, followed by a second manned station that becomes operational in 1994 as an OTV base and free-flyer tender.

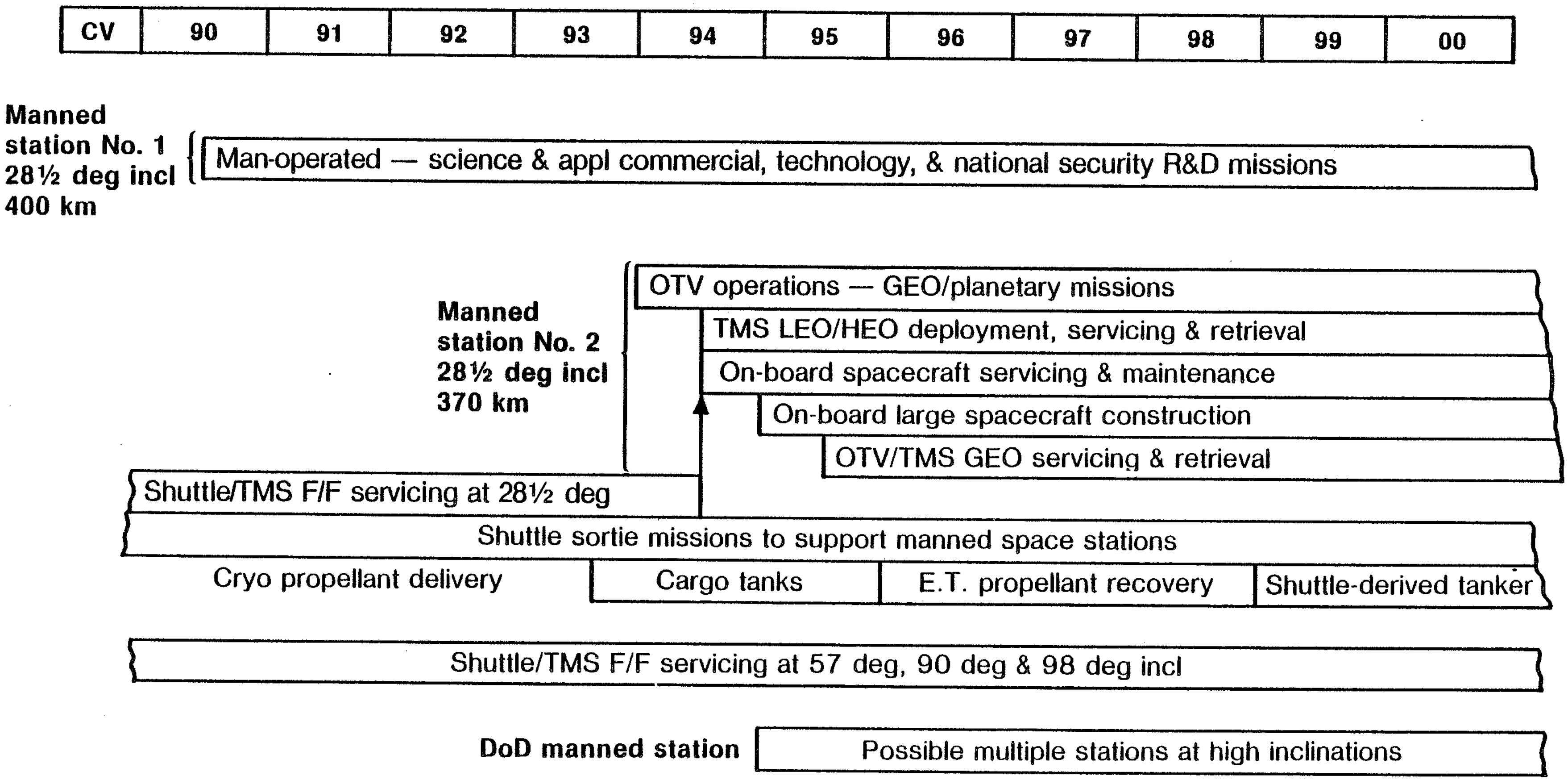
On-board large spacecraft construction would be implemented in 1995 followed by an OTV/TMS servicing and retrieval capability.

The Shuttle/TMS would provide LEO free-flyer servicing at 28.5° inclination until that function is implemented on Station No. 2. The delivery of cryogenic propellants to the OTV base could initially be provided using cargo tanks in the Shuttle orbiter until the ET propellant recovery technology was proven. Eventually a Shuttle-derived tanker would be required to support the growth in OTV launched traffic.

Due to the small number of free-flying satellites identified at the 57°, 90° and 98° inclinations, the Shuttle/TMS would continue to service these satellites through the end of the decade.

The DoD manned station requirements are vaguely defined at this time as shown.

PRELIMINARY SPACE STATION EVOLUTIONARY PROGRAM
Option 1



15112793-110

A second option is driven by the high potential benefits achievable with the OTV base function. In this scenario the OTV base development would be accelerated to provide an initial capability in 1991. This first manned station, however, would start off providing some limited man-operated missions capability to support technology development for OTV, satellite servicing, large spacecraft construction; operational life sciences research; commercial processes development; and some limited science and applications missions.

As Station No. 1 became fully operational, a second station would be placed in operation in the middle of the decade to support more extensive man-operated missions as that function was phased out of Station No. 1.

As seen here, the shuttle operations scenario would be the same as described for option 1.

There may be a need for an early DoD manned station that would allow national security R&D missions to be performed away from the predominantly civilian station. This station could support some early operational missions and provide technology development leading to future DoD manned stations.

GENERAL DYNAMICS
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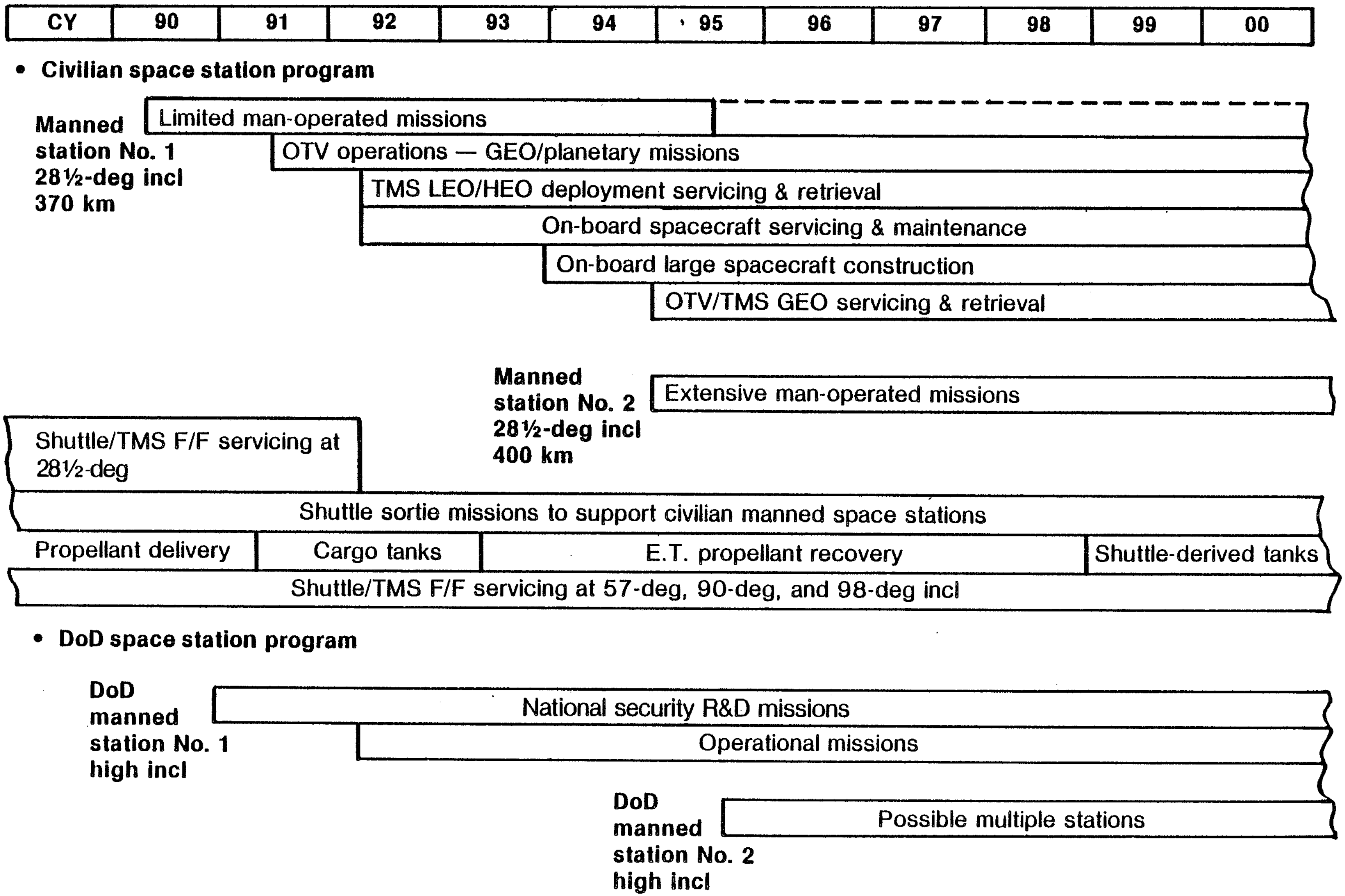
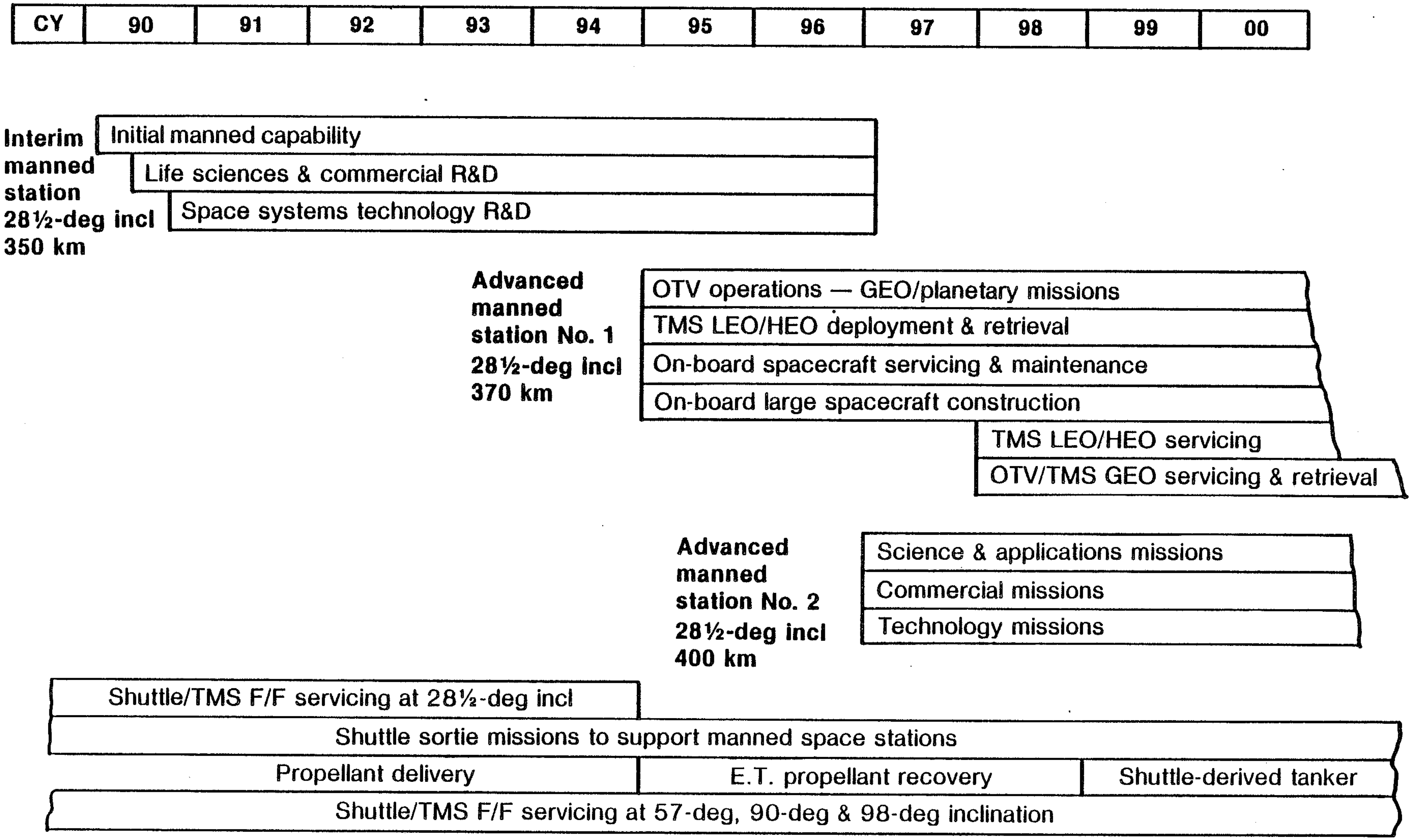
PRELIMINARY SPACE STATION EVOLUTIONARY PROGRAM
Option 2



15112793-130

The third evolutionary program option would be to provide an interim manned station capability in the late 80's or early 90's using proven technologies (Shuttle, Spacelab, etc.). This station would serve primarily as a development center for elements of advanced stations. Its functions would be to develop advanced station technology and hardware and eventually be used as a construction base to assemble the major elements of the advanced station. It would also allow new, unanticipated systems and processes to be developed that might significantly alter the planned Space Station System architecture. This would allow major changes to be implemented before completing the advanced stations.

PRELIMINARY SPACE STATION EVOLUTIONARY PROGRAM
Option 3



15112793-132

Mission implementation task progress to date and areas of effort during the next study interval are summarized on the facing chart.

MISSION IMPLEMENTATION SUMMARY

- Major system functional elements identified
- Functional analysis based on mission requirements will drive the definition of architectural options
- Space base OTV can provide significant reduction in cost of payload delivery to GEO
- OTV technology needs identified
- Preliminary space station evolutionary program options defined
- Effort planned prior to next review
  - Functional concepts & trades
  - Architectural options & trades
  - Evolutionary program plan & cost estimate
  - System business analysis

15112793-164

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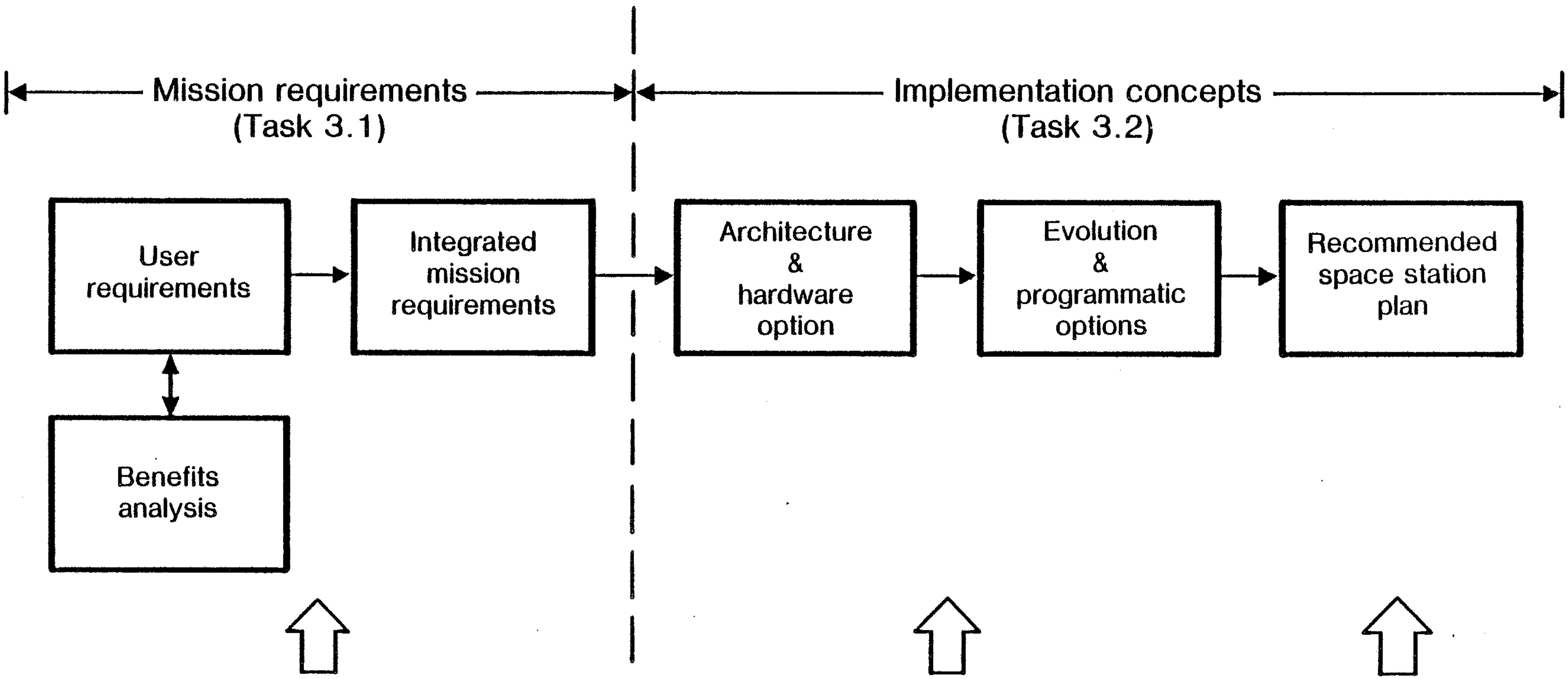
SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS
Midterm Briefing

	Presenter
Introduction	Don Charhut
Executive Summary	Otto Steinbronn
Mission Requirements	Warren Hardy/Dick Norris
Approach & Data Base	
Mission Requirements	
Integrated Mission Requirements	
Summary of Mission Requirements	
Mission Implementation	John Bodle
$\boxed{\textbf{Cost \& Programmatic Analysis}}$	Bob Bradley
Summary	Otto Steinbronn

15112973-8

The cost and programmatic analysis tasks to be performed in support of this study are depicted on the opposite chart. During the Mission Requirements effort (Task 3.1) economic benefits analyses have been undertaken to evaluate and support requirements development. During the analysis of the implementation concepts task (Task 3.2), preliminary rough order of magnitude (ROM) Life Cycle Costs will be developed for comparison and evaluation of the architecture and hardware options as well as the evolution and programmatic options. ROM costs for the preferred Space Station plan will be estimated together with incremental cost benefits of the evolutionary scenario and the impact of schedule variations.

TASK 3.3 — COST & PROGRAMMATIC ANALYSIS TASKS



- Economic benefits analysis
- Financial analysis
- User charge analysis

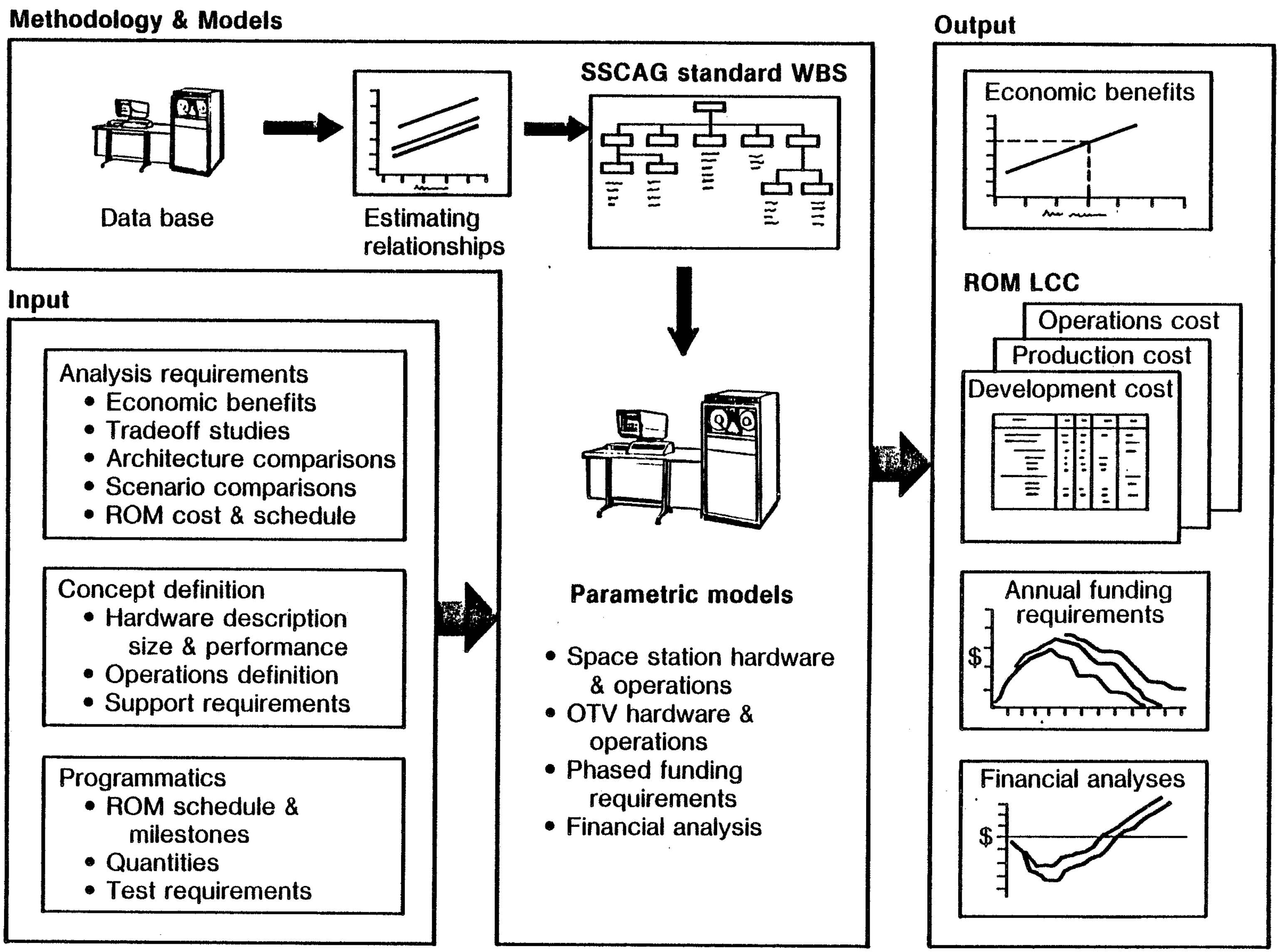
- Trade study support
- ROM LCC cost comparisons
  - —Hardware
  - —Architecture
  - —Programmatic options/ scenarios
- Financial option analysis

- ROM LCC & schedules
- Schedule variations
- Incremental cost benefits

15112793-38

The approach to be used to develop cost and economic data is shown on the facing chart. Individual parametric models are used to produce the required economic benefits, hardware and operations life cycle costs and financial analyses. The model used depends, of course, upon the analysis requirements and will be driven by the concept definition (hardware, operations, and support requirements) and programmatics information (schedules, milestones, quantities, etc.)

COST & ECONOMIC METHODOLOGY



15112793-39

The basic groundrules for the cost and programmatic analysis have been provided by NASA. Additional groundrules have been established to facilitate the cost estimating effort.

COST ESTIMATING GROUND RULES

- FY84 dollars
- Cost submitted at subsystem level (or at level estimated)
- Schedules submitted at module level with major subsystem milestones
- Milestones in terms of FY1, FY2, etc (instead of date)
- DRD MF003M format suggested
- SSCAG standard WBS suggested
- Prime contractor fee excluded
- STS transportation cost per FY86-FY88 pricing policy
- Operations costs for 10 years (or as applicable)
- Cost excludes SRT & advanced development unless specifically called for
- Cost excludes NASA operations & IMS

Relative importance of Space Station functions in providing economic benefits to the various user groups is illustrated. Space-based OTV appears to offer the broadest and most substantial economic benefits, followed closely by LEO servicing and man-operated function. National Security and Commercial communications and materials processing are the primary beneficiaries.

ECONOMIC BENEFITS ANALYSIS

Space Station Capability

	Space-based OTV	LEO servicing	Man-operated function	GEO servicing	Co-orbiting free-flyers	Satellite logistical support/resupply	On-orbit assembly	Data processing/ communications	
National security	●	●		○		○	○	○	10
Commercial communications	●		○	●		○	○		9
Commercial materials processing in space		○	●		●	○			8
Astrophysics	○	●			○	○		○	7
Technology development	○	○	○	○			○	○	6
Life sciences			●						3
Commercial Earth & oceans observations	○	○							2
Earth & planetary observations	○	○							2
Environmental observations	○	○							2
	11	11	8	5	4	4	3	3	

● Significant benefit (3 pts) ○ Moderate benefit (1 pt) ☐ Minor or no benefit (0 pts)

15112793-101

A preliminary analysis of the major economic benefits of a Space Station shows the space-based OTV to have the greatest quantifiable impact. The SBOTV would support a mature commercial market - launch of communications satellites - and would offer cost savings to most other users as well. Man-operated and man-tended free-flyer functions have the potential for equally significant economic benefits, but these benefits appear to be more difficult to quantify and perhaps longer-term in nature.

Based on these preliminary observations the study strategy was to initially perform a detailed analysis of the SBOTV economic benefits, and to use these benefits as an early indicator of the economic viability of a Space Station. Future efforts will be aimed at identifying and evaluating other areas of potential economic benefits, e.g., materials processing in space (MPS).

SPACE STATION MAJOR ECONOMIC BENEFITS
Preliminary Analysis

I. Space-based OTV function

- Supports mature commercial market — launch of communications satellites
- Offers versatility & performance factors desirable to science, applications & national security users
- Appears to offer greatest quantifiable space station economic benefits

II. Man-operated/man-tended free-flyer functions

- Offer significant potential benefits in STS operating efficiency
- Technology advances & space production (commercial MPS) have great long-term potential
- Economic benefits most difficult to quantify

III. Strategy

- Perform detailed analysis of economic benefits of space-based OTV
- Use SBOTV benefits as preliminary measure of space station economic viability
- Identify general areas of further space station benefits to be determined

Man-Operated Function

- Permanent basing of Spacelab-type module at LEO Space Station eliminates need for Shuttle launch of Spacelab. Launch and LEO integration of replacement experiments and supplies should cost only about one-third of typical Shuttle-Spacelab mission, due primarily to reduced cargo bay use and Shuttle time-on-orbit. Savings per typical one-week equivalent Spacelab mission are conservatively estimated at $50 million.
- Reduction of time required for commercialization of applications research, particularly in materials processing in space, should result from continuous laboratory operations. Economic benefits to be determined.
- Technology development and life science advancements should yield as yet unquantified economic returns.

Servicing of LEO Free-Flyers

- LEO-basing of TMS will save a minimum of $5 million in Shuttle transportation costs per TMS mission. Hydrazine propellant for TMS is assumed to cost $1500/lb for delivery to LEO.
- Reduction of Shuttle time-on-orbit will result from space-basing of servicing operations.
- Extension of operating life of LEO assets could provide annual benefits of tens of millions of dollars.

Space-Based OTV

- Greatest economic benefit of Space Station appears to be reduction in launch costs to high orbits with a reusable space-based OTV. SB OTV operating costs are estimated to be 20-50% lower than Shuttle-Centaur, depending on cost of propellant delivery to LEO. Detailed analysis of OTV costs is presented in costs and programmatics section.
- Sale of propellant recovered from ET during standard Shuttle missions can generate additional revenue and cost-reduction opportunities for all Shuttle users. Nominal estimates of 28,000 lb of propellant recovered and sold to OTV users at $250/lb yields benefit of $7 million per Shuttle Flight.
- Based on projected cost per transponder-year over $250,000, among other factors, servicing of geo-synchronous communications satellites and other high-orbital assets should provide great economic benefits, to be determined.

SUMMARY OF SPACE STATION ECONOMIC BENEFITS
Preliminary Analysis

	Number of Missions (annual)	Benefit per Mission	Total Annual Benefit	Primary* Beneficiaries
I. Man-operated function				
• Reduction in spacelab module carrying charges	6	$50M	$300M	S
• Reduction in time required for commercialization of R&D processes	TBD	TBD	TBD	S,C
• Technology development & life science advancements	TBD	TBD	TBD	S,C
II. Servicing of LEO free-flyers				
• Reduced TMS carrying charges	15	$5M	$75M	S,D
• Reduction in shuttle time-on-orbit	TBD	TBD	TBD	S,D
• Extension of operating life of LEO assets	TBD	TBD	TBD	S,D
III. Space-based OTV				
• Reduction in payload launch costs to HEO/GEO	15	$54M	$815M	C,D
• Shuttle-user benefits from ET propellant recovery	24	$7M	$168M	S,C,D
• Extension of operating life of HEO/GEO assets	TBD	TBD	TBD	S,C,D
Totals	60 +	$22.6M (Average)	$1360M +	

Conclusion: Identified net economic benefits to space station users exceed $1.3 BILLION annually. Economic benefits TBD could raise this figure significantly.

*Primary beneficiaries: S = Science & applications C = Commercial D = Defense

15112793-100

It appears that the space based OTV function supports a mature commercial market, i.e., the launch of communications satellites, and offers versatility and performance factors desirable for the science and applications and National Security users. In addition it appears to offer the greatest quantifiable Space Station economic benefit.

Although the man-operated/man-tended free flyer functions offer significant potential benefits in STS operating efficiency, technology advancement and space production (commercial MPS), and have great long term potential, the economic benefits are more difficult to quantify.

It was desired, therefore, to perform a more detailed analysis of the economic benefits of the space based OTV and use those benefits as a preliminary measure of the Space Station viability.

SPACE-BASED OTV ECONOMIC BENEFITS
Preliminary Parametric Analysis

Objective
- Identify drivers
- Determine sensitivity
- Determine economic viability

Scenario
- SBOTV "operating authority" will buy SBOTVs propellant, conduct launch & maintenance services & sell transportation to GEO
- SBOTV will be maintained & operated on or from the space station
- Propellants & payloads are delivered via the STS
- Propellants are acquired either as ET residuals or by dedicated transportation

Analysis
- Examine direct operating costs plus vehicle hardware cost
- Determine economic benefits in terms of savings over competitive systems
- Compare economic benefits with potential SBOTV development cost

Estimates of the costs to deliver 150,000 pounds of payload annually to geosynchronous orbit with a space-based OTV are compared with costs of potential competitors. Space-based OTV has a significant cost advantage, due primarily to its reusability and a reduction in Shuttle costs from space-basing of the upper stage. Propellant for the higher-performance space-based vehicle is recovered from the Shuttle External Tank or delivered to LEO via dedicated ET "tanker", at an estimated cost of $250/lb. The STS portion of space-based OTV cost is based on an assumed Shuttle load factor of .225 for a typical 10,000-pound OTV payload; this cost could be reduced if payloads are optimized for Shuttle pricing policy. Hardware and launch services for space-based OTV include $1M hardware ($60M unit cost ÷ 60 flights per vehicle), $0.75M transportation (1/2 Shuttle flight for delivery of OTV to LEO), and $15M operations and refurbishment per flight. Shuttle-based and space-based reusable OTV's both utilize aerobrake-return concept.

DIRECT OPERATIONAL COST COMPARISON
Transportation to GEO

Transportation System	Cost per Flight (1984 M$) Hardware & Launch Services	STS	Propellant Delivery	Total	Total Annual Cost*
Delta	30	0	0	30	4,020
Commercial Atlas/Centaur	45	0	0	45	3,245
Commercial Atlas II/Centaur	75	0	0	75	2,010
Shuttle/PAM-D	6	17	0	23	3,600
Shuttle/IUS	75	83	0	158	5,925
Shuttle/Centaur	34	83	0	117	1,570
Shuttle-based reusable OTV	13	83	0	96	2,010
Space-based reusable OTV	17	25	8	50	755

*Based on 150,000 lb/year to GEO

Likely competitor	$1,570M
Space-based OTV	755M
Direct economic benefit	815M

15112793-43

Analysis of sensitivity of space-based OTV benefits to key assumptions shows propellant delivery cost, traffic model, and competitor launch costs to be the key variables. OTV operations costs, hardware costs, and lifetime are not critical factors.

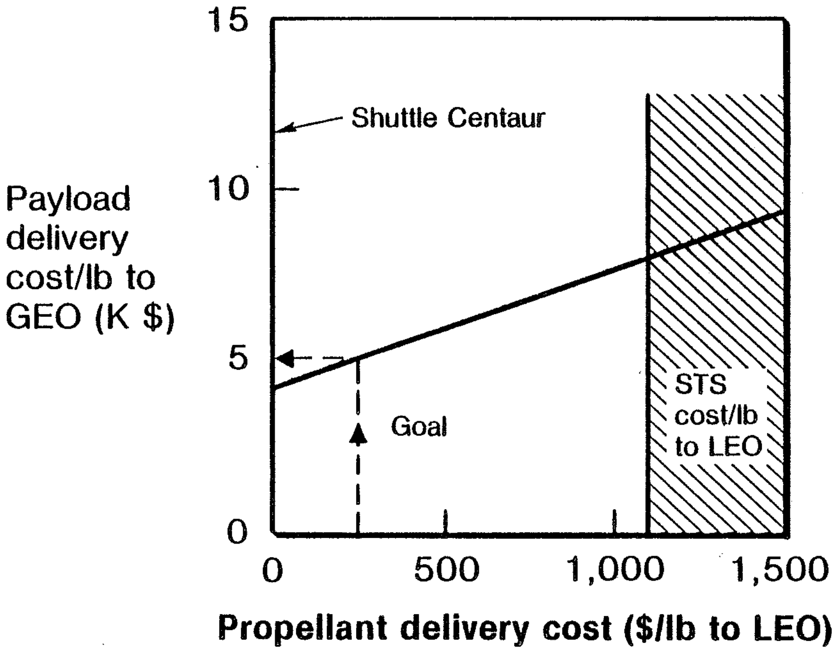
SBOTV PARAMETER SENSITIVITY RANGE

Performance/Cost Parameter	Low Value	"Baseline" Value	High Value	Sensi-tivity
Propellant delivery cost to LEO ($/lb)	0	250	1,500	High
Traffic model — P/L to GEO (klb/yr)	80	150	250	Med
Competitor launch cost ($/lb to GEO)	8,500	10,000	20,000	Med
Direct operating cost ($M/flight)	10	15	20	Low
Lifetime (No. of flights)	30	60	100	Low
Hardware unit cost ($M)	30	60	75	Low

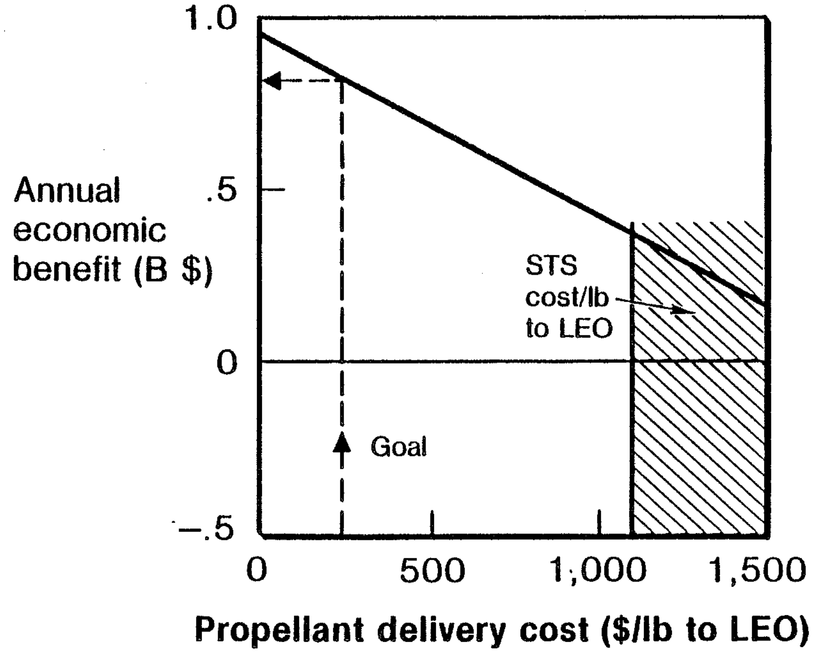
Detailed sensitivity analysis shows propellant delivery costs to be a major influence on the economics of space-based OTV operations. Delivery of propellant via standard Shuttle launch (at $1100-1500/lb) reduces economic benefits considerably, although SBOTV maintains its advantage over its closest competitor, the Shuttle-Centaur. Reduction of propellant cost to $250/lb. gives SBOTV its substantial $8000M/year economic advantage although a doubling of propellant cost ($500/lb) still permits SBOTV to operate at roughly half the cost of Shuttle-Centaur.

SBOTV SENSITIVITY TO PROPELLANT DELIVERY COST (1984 $)

Payload delivery cost vs propellant cost to LEO



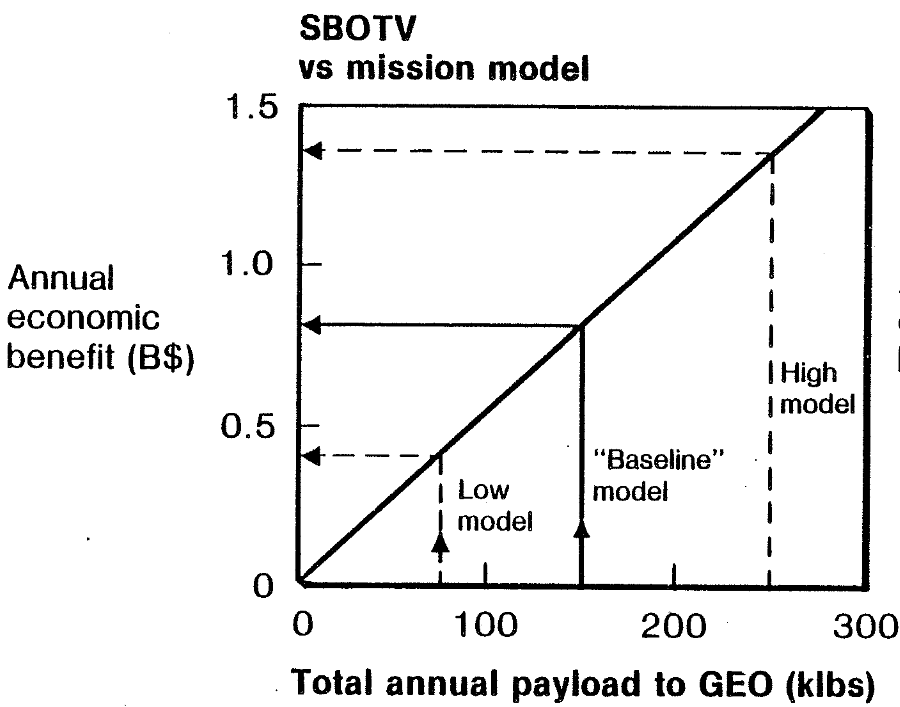
Economic benefit vs propellant cost to LEO

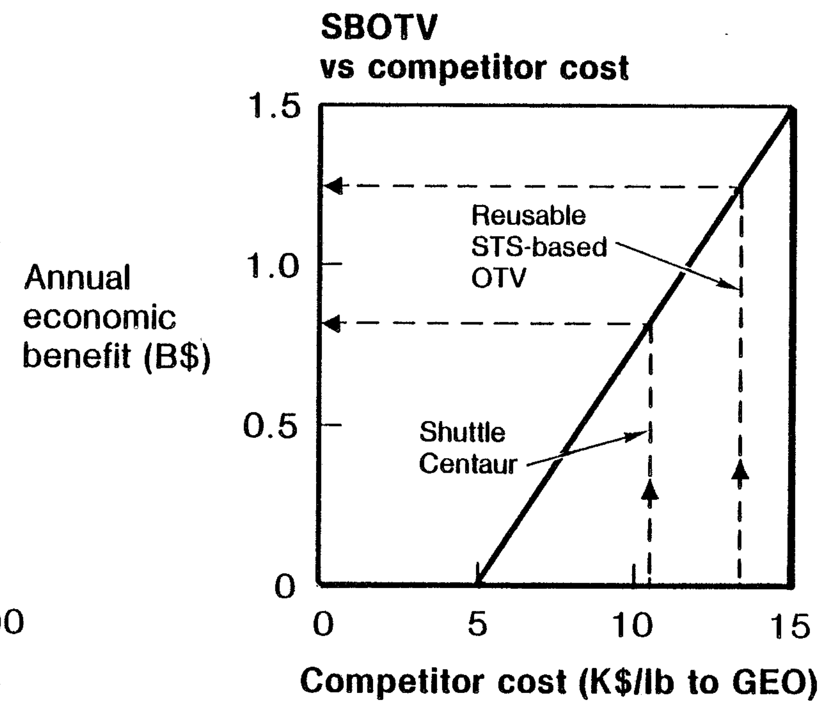


15112793-45

Sensitivity of SBOTV economic benefits over nearest competitor to changes in demand and competitor cost are moderate. Annual economic benefits are reduced by 50% in worst case "low" mission model, while high mission model offers potential 75% increase in annual benefits. SBOTV advantage over other competitors, such as Reusable STS-Based OTV, is even greater than savings over Shuttle-Centaur.

SBOTV ECONOMIC BENEFITS SENSITIVITY
(1984 $)

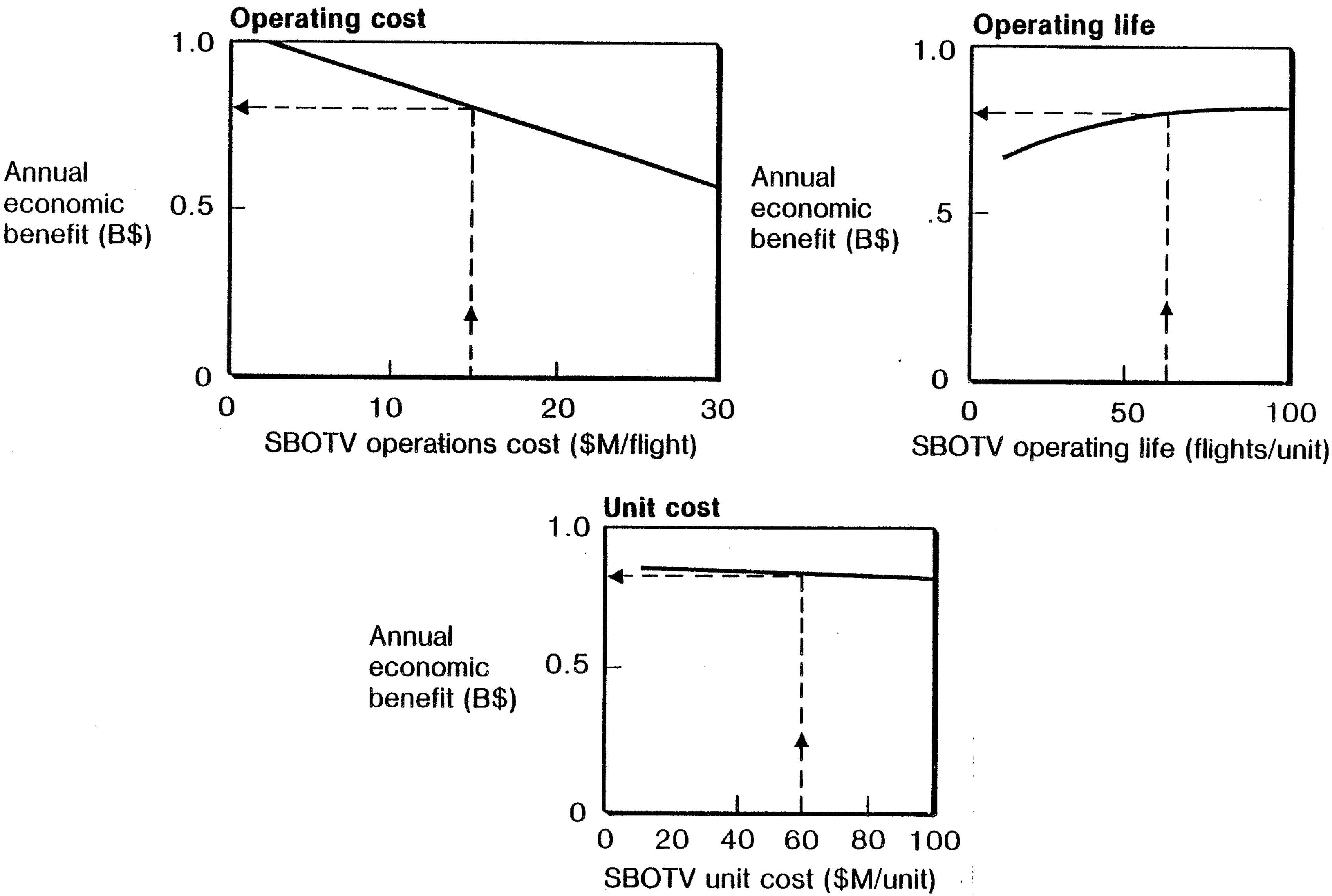




15112793-46

Annual benefit of space-based OTV over closest competitor is shown to have a low sensitivity to recurring cost factors such as OTV operating cost, operating life, and unit cost. A doubling of OTV operations costs reduces economic benefit by about 25%, while doubling of OTV operating life and unit cost have minimum impact on OTV economic advantage.

SBOTV ECONOMIC BENEFITS SENSITIVITY
(1984 $)

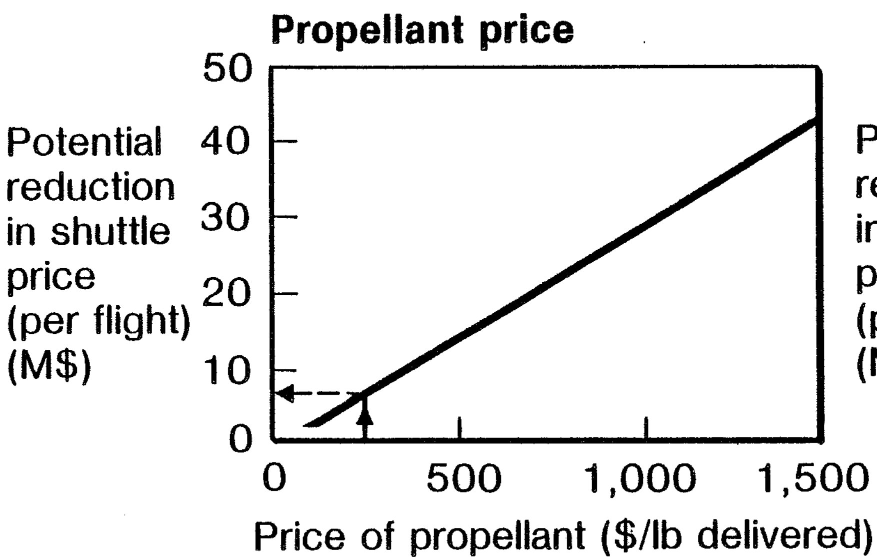


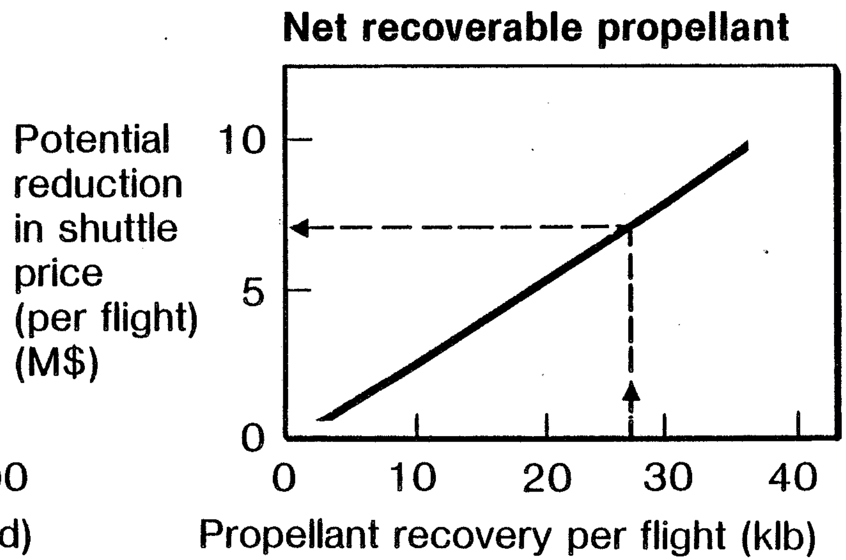
15112793-47

Recovery of propellant from Shuttle external tank could extend the economic benefits of the space-based OTV to all STS users. OTV users, possibly through an "OTV Operating Authority", pay $250/lb for propellant, which is recovered from the external tank on most Shuttle flights. With nominal net recovery of 28,000 lb propellant per flight, $7M in revenue is generated, which could be passed along to Shuttle users in the form of price reductions. Sensitivity charts show that further reductions in Shuttle price could be created by increasing propellant recovery or raising the propellant price to OTV users, although the latter option would diminish the economic benefits to OTV users and operators. Flexibility in pricing policy for recovered propellant could provide NASA with a means of balancing benefits to Shuttle and OTV users.

ECONOMIC BENEFITS TO STS USERS
(1984 $)

Benefits of propellant recovery from shuttle external tank





Conclusion

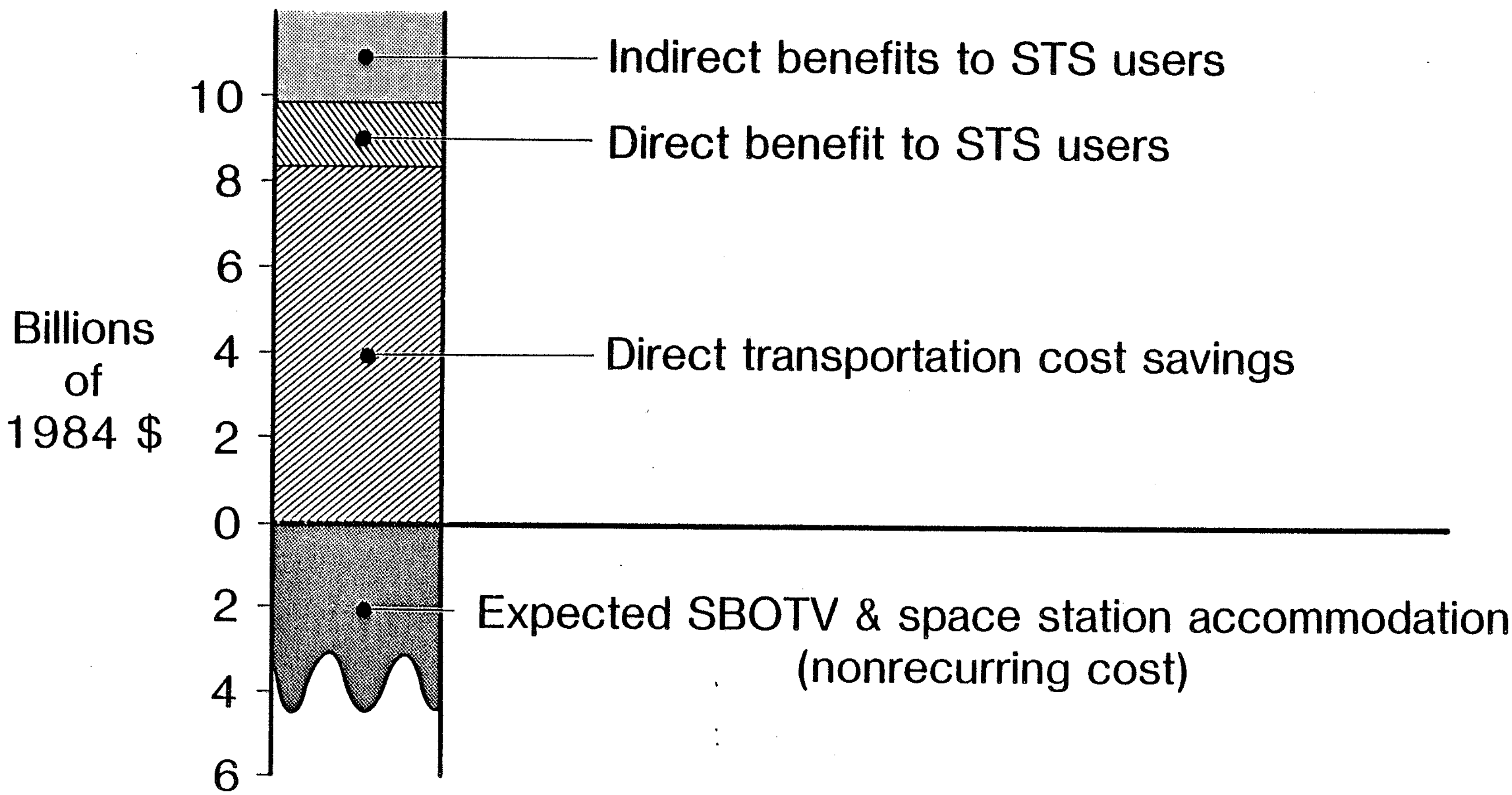
Recovery of OTV propellant from shuttle external tank could provide NASA with a means of significantly reducing shuttle prices

The facing chart graphically depicts the expected benefits over a 10 year period of mature OTV operations (say 1995 to 2005) at the equivalent of 150,000 lb/year to GEO. This includes both the direct transportation cost savings as well as the direct benefits to the STS users in terms of reduction in Shuttle price per flight. There should also be less quantifiable benefits to the OTV users in terms of savings due to prelaunch checkout, relaxed envelope limitations, etc.

These benefits may then be compared with the expected non-recurring cost of the space-based OTV and its Space Station accommodations, potentially in the area of 3.5 to 4.5 B$. It should be noted that much of these benefits do not, of course, represent funds available for financing this capability, but only that there is a net positive benefit from the overall economic point of view.

SUMMARY OF SBOTV ECONOMIC BENEFITS

10 years operations at 150,000 lb/year to GEO

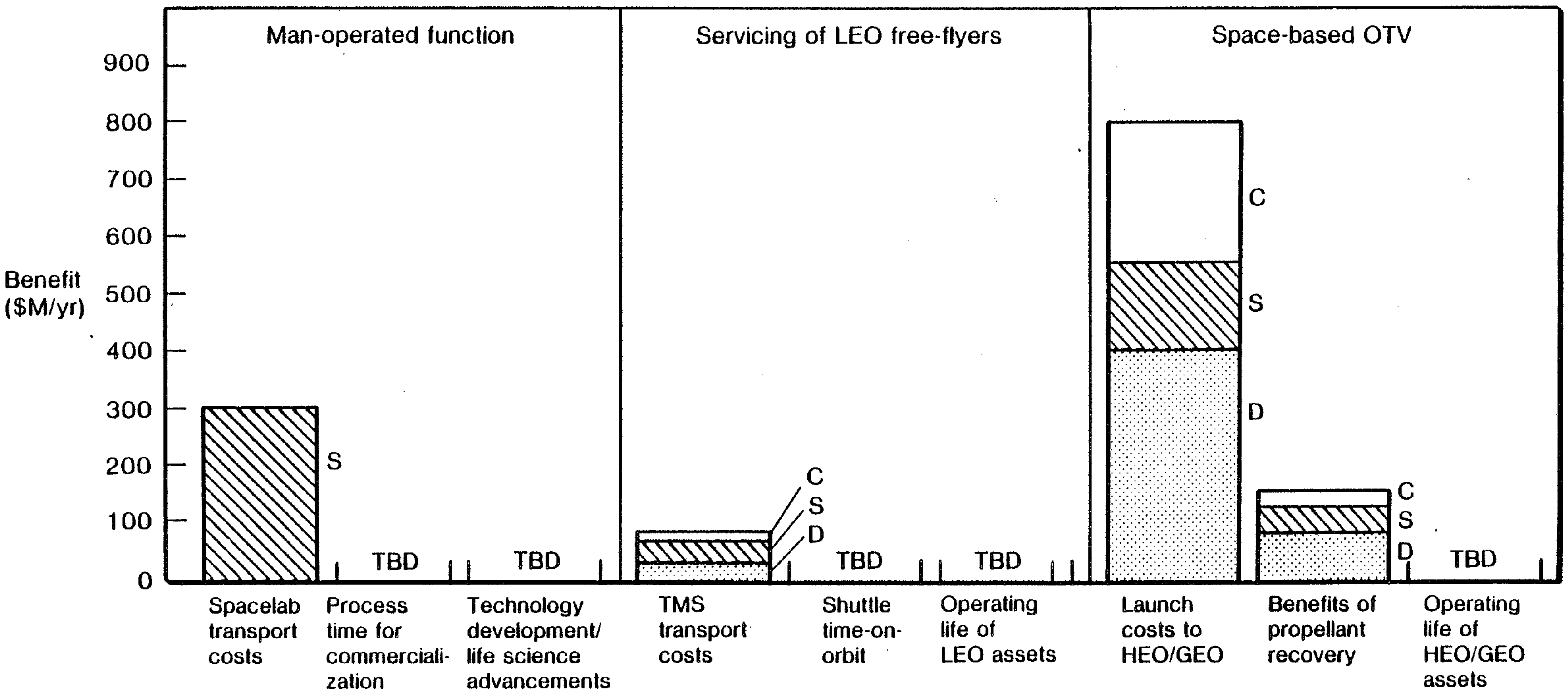


15112793-52

Graphical depiction of preliminary economic benefits data shows the prominence of the space-based OTV, but illustrates an equally important point: the Space Station offers substantial economic benefits to all types of users. Science and applications users appear to benefit most heavily, but other benefits to be determined, particularly in extending the operating life of orbital assets, should be particularly important to commercial and national security users.

GENERAL DYNAMICS
Convair Division

ECONOMIC BENEFITS SUMMARY
Preliminary Analysis



Totals

C — Commercial = $298 M (+ TBD)/yr

S — Science & applications = $583 M (+ TBD)/yr

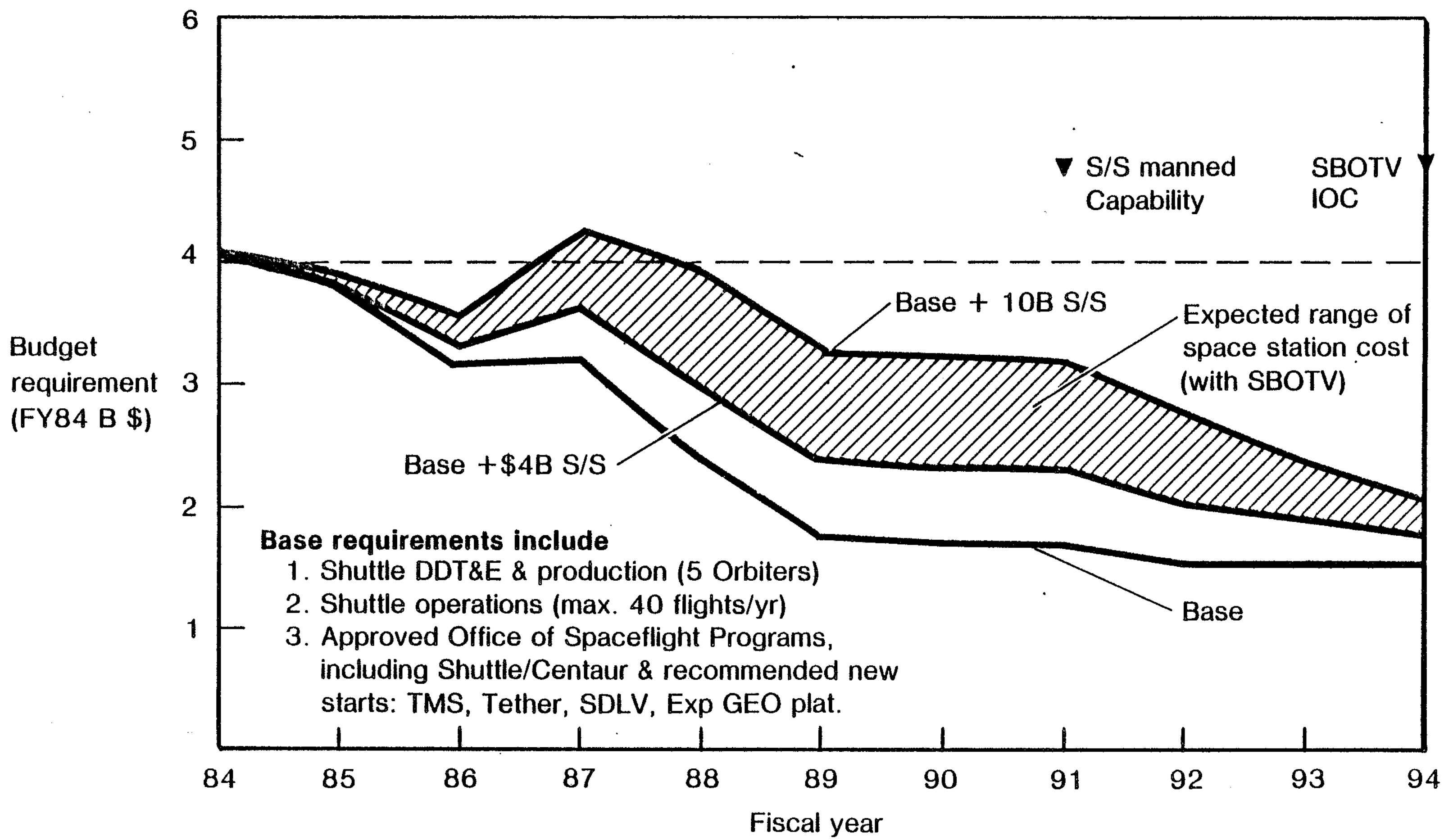
D — Defense = $478 M (+ TBD)/yr

Total = $1359 million annual economic benefit (+ TBD)

15112793-99

Projected run-out of NASA Office of Spaceflight programs, including completion of DDT&E on 5-Orbiter Shuttle fleet and non-reimbursable Shuttle Operations costs through 1994 (maximum 40 flights per year). Also included in base are ongoing programs in Space Transportation, such as Advanced Planning and Engineering/Technology Development, plus four potential new starts: Teleoperator Maneuvering System, Tethered Satellite, Shuttle-Derived Launch Vehicle, and Experimental Geostationary Platform. Shaded area shows impact of a Space Station program on budget requirements, ranging from a $4 billion Space Station program (lower bound of shaded region) to a $10 billion program (upper bound). The $4-10 billion range represents roughly the non-recurring cost range for a Space Station with an operational space-based OTV capability.

IMPACT OF SPACE STATION ON NASA SPACE TRANSPORTATION BUDGET REQUIREMENTS



1512793-49

A preliminary look at use charges for Space Station users is being undertaken. When an organization is going to conduct experiments or start a manufacturing operation on earth there is need of a room or building (physical accommodations), lab or factory workers (crew time), electric company hookup (electrical power), phone company hookup (communications), computer or on-line service (data processing), etc. In a similar scenario potential use charges for the principal resources on a Space Station are being evaluated.

The various constituents of the crew time charge is shown for one particular scenario. It is interesting to note that the principal cost is associated with the transportation of the logistic material to sustain the crew. The development of a Closed Ecological Life Support System (CELSS) as facilitated by the Space Station would provide a major economic benefit. The costs shown are direct operating costs and amortization of hardware or development of crew-related systems has not been included at this time.

PRELIMINARY SPACE STATION USER CHARGES
(1984 $)

Resource	Use Charge
Transportation	$1,720/lb
Crew time	$8,450/hr
Physical accommodations	TBD/cuft
Electrical power	TBD/kwh
Communications	$161/min
Data processing	TBD/CPU

Crew time use charge

Cost/man/90 days $4,426M

- Pay & allowances
- Initial training
- Retraining
- Crew transportation
- Logistic material
- Logistic transportation
- Ground support
- Habitability/LSS maintenance

Time available/90 days 525 hrs
Beneficial manhours
Available/man

Use charge (cost based)
Direct operating = $8,450/hr
+ Related production = TBD
+ Related development = TBD

15112793-50

The facing page summarizes the main conclusions at this time. The current economic benefits activity will continue through the study. In addition, ROM LCC costs estimates will be generated to support comparison and evaluation of the mission implementation phase of the study.

PRELIMINARY CONCLUSIONS

- The space-based OTV appears to offer a relatively firm, near term & substantial economic benefit
- Other space station functions & missions (e.g. MPS, satellite servicing,) have great potential, but the economics are more difficult to quantify credibly because of requirement & programmatic uncertainty
- Additional analysis should focus on
  - Substantiating the economics of the space-based OTV
  - Examining methods of quantifying other space station capabilities
  - Identifying the key issues & drivers of space station economics

15112793-163

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SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS
Midterm Briefing

	Presenter
Introduction	Don Charhut
Executive Summary	Otto Steinbronn
Mission Requirements	Warren Hardy/Dick Norris
Approach & Data Base	
Mission Requirements	
Integrated Mission Requirements	
Summary of Mission Requirements	
Mission Implementation	John Bodle
Cost & Programmatic Analysis	Bob Bradley
Summary	Otto Steinbronn

15112973-9

The first phase of our study has clearly shown that a Space Station will provide extensive economic and performance benefits to a wide range of planned missions. The most significant benefits, both economic and performance, accrue in the case of an OTV base. The existence of an already-established extensive communication satellite market allows benefits in this area to be realistically quantified. Economic benefits exceeding $1.3 billion per year have been identified, the majority of which are attributable to the OTV base. This return will allow rapid payback of Space Station investment.

Other economic benefits in areas such as materials processing and earth/ocean observations have been identified; further efforts will be devoted to the quantification of these benefits.

MAJOR STUDY CONCLUSIONS
Phase I

- A manned space station will provide major performance & economic benefits to a wide range of missions planned for the early 1990s
- Development of a man-operated OTV base provides the most significant & the most quantifiable economic benefits
- Economic benefits quantified to date exceed $1.3 billion per year, offering potential for rapid payback of space station investment
- Man-operated facilities for commercial activities such as materials processing, communications & Earth/ocean observations have a tremendous economic potential — quantification is more difficult

15112793-143

Our studies also show that a Space Station can directly reduce the cost of Shuttle launches through the sale of propellant recovered from the ET. In addition, using the Shuttle primarily for transport of spacecraft, etc., directly to a Space Station will reduce on-orbit time thereby significantly improving Shuttle utilization.

Preliminary studies have also shown that joint NASA/DoD usage of a Space Station is feasible, in particular in early phases, and that significant cost and performance benefits can be expected. Joint NASA/DoD usage of a station for operational DoD missions appears less certain; this will be investigated more thoroughly in our next phase of study.

A definite interest exists within the commercial community for a Space Station, but extensive interaction will be required to strengthen and broaden this interest. It is expected that the definite availability of a Space Station would stimulate interest very significantly.

MAJOR STUDY CONCLUSIONS
Phase I (continued)

- A space station can potentially reduce the cost of shuttle launches & significantly improve shuttle utilization
- Combined NASA/DoD utilization of an initial space station provides economic & technical benefits — preliminary studies of operational DoD missions indicates need for a separate station(s)
- Continued discussions are expected to develop major operational uses & benefits of a space station to DoD
- Commercial interest in a space station does exist but extensive user interaction is necessary
- An in-place facility (or firm availability date) will provide a major stimulant to potential commercial users

The second phase of our study will proceed as defined in our study plan. Particular emphasis will be placed on the three areas identified on the facing page.

Based on the user data which we have now developed, we will continue to interact with the broad user community and develop a maximum of interest and support for a Space Station.

Our economic analysis will focus on more thoroughly quantifying the economic benefits available from a Space Station. This will include an in-depth evaluation of the projected OTV base benefits, as well as a more extensive look at other areas of large potential benefits such as for materials processing and earth/ocean observations.

The major task during the second phase of study will be the final definition, evaluation and selection of architectural concepts and program evolutionary options. This task will be carried out based on requirements data now available, or as augmented during the second phase of study. Extensive economic analysis will support this activity. Discussions with user representatives will continue to assure that any concepts developed meet the objectives of a maximum number of missions.

PLANS FOR COMPLETION OF SECOND PHASE OF STUDY

- Continue to strengthen user involvement
  - Follow up on negative as well as positive responses to our user brochure
  - Accelerate interaction with foreign & DoD communities
  - Support NASA in keeping level of awareness of space station opportunities high among potential commercial users
- Refine economic analysis
  - Verify projections of large benefits from a space-based OTV
  - Quantify other economic benefits, such as for materials processing & Earth/ocean observations
  - Generate ideas for creative government/industry partnerships to overcome economic obstacles
- Develop space station architectural/evolutionary options
  - Determine appropriate balance between low initial cost & high early economic return
  - Carry out extensive marginal cost/benefits analysis to assure value of added capabilities
  - Maintain interaction with user community to ensure their support of selected options

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